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Energy comparison of under floor air distribution heating ventilation and air conditioning systems in office buildings

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by

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ABSTRACT

The purpose of this paper is to compare energy consumption with under floor air distribution systems for office buildings, specifically a call center application.

The building being modeled will have an HVAC system that utilizes an underfloor air distribution system (UFAD). This type of system allows air to be introduced into the plenum space under the floor. The air comes up through the floor into the space through plenum space pressurization. The air is then taken out of the space up high and returned back to the air handling unit.

The three systems reviewed for delivery of the air to the underfloor system (comparing energy consumption on the UFAD systems) are roof top units (RTU) with full economizers, boilers and chillers and a ground source heat pump (GSHP). These systems are being modeled as a heating and cooling plant for the UFAD system. The first costs as well as the energy consumption have been analyzed to determine simple paybacks from system to system listed above.

It was calculated that the RTU has the lowest initial cost at $1,492,049, the boiler / chiller was next at $1,769,069 and the highest cost system was the GSHP at $2,700,002. The systems energy cost per year were calculated to be; RTU - $77,440, boiler / chiller - $46,782 and GSHP - $8,557. The system paybacks from the RTU versus the boiler / chiller were 9 years, the RTU versus the GSHP was 17.4 years and the boiler / chiller versus the GSHP was 24 years.

CHAPTER 1. INTRODUCTION

INTRODUCTION

In the past several years one of the new buzzwords for conditioning spaces, where heating, cooling, or ventilation is concerned, has been under floor air distribution (UFAD). This type of system provides air directly to the office workers in their respective workstations. It typically gives the occupant control over the speed and direction of the air being supplied into their work space. Under floor air distribution is being used in all types of buildings, but will be addressed in this paper for the use of a call center with some office space.

Under floor air distribution is a means of providing air from an air handling unit down to a raised floor and up into a conditioned space above. The air is then removed from the conditioned space and returned to the air handling unit housed in the ceiling, or high above the raised floor.

TEMPERED AIR DELIVERY SYSTEMS

Under floor air can be heated and cooled using several methods. In a traditional Heating, Ventilation and Air Condition (HVAC) system, the tempered air is being provided from overhead. The air is then mixed into the space to give the desired space temperature. In a UFAD system tempered air is mixed in the floor space and delivered to the occupied space at a desired temperature. It is believed that by using a UFAD system twenty to thirty percent energy consumption can be saved (Bauman 2003). A sample of the floor system, where air is being provided from the floor to temper the space is shown below in diagram 1.

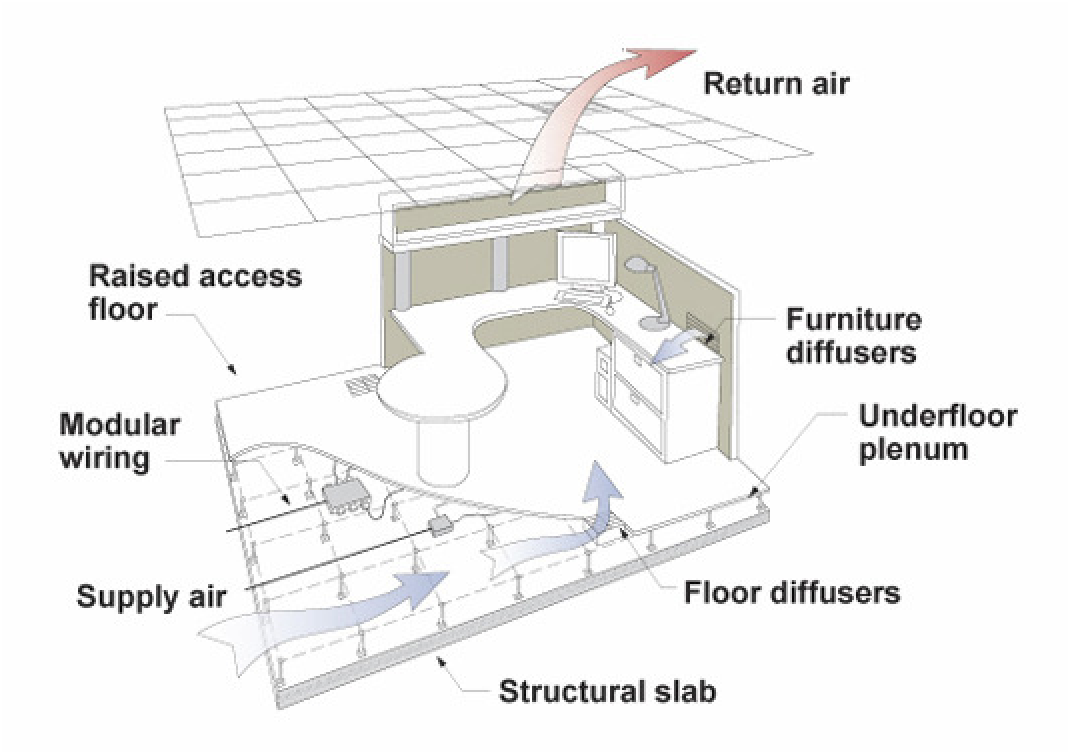

Diagram 1 (Bauman 2003)

Three of the specific for providing tempered air to a UFAD system are being compared to each other for energy usage and savings. The three methods used in this review are roof top units, a boiler and chiller plant with an air handling unit and a ground source heat pump system. Each system can provide heating and cooling below the floor UFAD space conditioning. The methods chosen are those typically desired by building owners for office spaces and call centers addressed. They will be compared to each other for energy usage and savings.

ENERGY EFFICIENCY PROJECT

UFAD first began to be utilized in the Sioux Falls, SD area for HVAC several years ago

(Clayton 2007). Building owners were starting to look for a more energy efficient way to heat and cool their buildings. While using more energy efficient equipment, such as ground source heat pumps were becoming common were ignoring the supply air from a UFAD system and continued to work only with traditional overhead sources. In addition to efficiency concerns, owners were looking for ways to keep the employees happy by giving them the ability to adjust the airflow in their space as well as create a way to avoid cold air dropping on the occupants.

As energy efficiency issues were further, the UFAD system began to replace the traditional overhead system for the call centers. While this saved energy, as mentioned above, savings were explored further by supplying air under floor, but with a more energy efficient air handling unit system UFAD systems explore further energy efficiencies were explored. There are limitless systems for the air handling unit of a UFAD, but three specific systems are typically used. The systems are roof top units, a boiler / chiller plant with an air handling unit and a ground source heat pump system.

SCOPE AND METHODS OF THE PROJECT

The project undertaking is to address which of the three systems mentioned above with a UFAD is the best option for the owner of the office building, more specifically, the call center. It will be assumed that the project costs for the raised flooring will remain the same for each type of system. The capital costs of each system as well as the energy costs of the systems will be compared. This will be done using an actual project that has been constructed within the last year as well as utilizing software provided by Tate Flooring

Company (Tate 2007). The mechanical contractor and mechanical supplier have agreed to provide actual costs for comparison purposes. The energy calculations, for both gas and electric will be determined using the local suppliers in the Sioux Falls, SD area.

SIGNIFICANCE OF THE PROJECT

As energy consumption and energy efficiency become widely recognized, and building owners become educated, the need to articulate the different system's capital costs, energy consumption and payback associated with each increases. In some areas the government is beginning to mandate the use of more energy efficient systems. Owners want to be able to determine the costs involved for their system and how many years before their investment is paying back.

DEFINITION OF TERMS

Air Dams – A way for air to be routed from a central air handler to a space farther away than the allowed design criteria. Sheet metal is placed on the sides (pedestals) of the raised floor, on the concrete floor (the bottom) and on the actual concrete flooring (the top) to create a duct in the underfloor system. Placing the sheet metal on the sides creates the air dam.

Air Handling Unit - A mechanical device to deliver the clean air to the space and pull the dirty return air from the space being conditioned.

Air Handling Unit System – A heating and cooling system that utilizes an air handling unit to pressurize the underfloor plenum and then utilize the ceiling as a return.

Boiler – A mechanical device to make hot water or steam. A boiler has different methods to make the hot water; typically natural or LP gas or electric.

Boiler and Chiller Plant – The system for making hot water and chilled water for conditioning the building. The boiler and chiller are typically located in the same location.

Building Owner – The person, group of people or business that owns the building.

Call Center – A building predominantly made up of cubicles on the inside and offices around the perimeter. The people working in the cubicles typically answer phone calls for the majority of their work.

Chiller – A mechanical device used to produce cold water (chilled water) to be used with an air handling unit for cooling the space.

Conditioned Space – A room or area that is heated or cooled to a pre-set temperature, typically this temperature is 70 degrees in heating and 75 degrees in cooling (ASHRAE 1992).

Constant Air Volume control (CAV) – A method of providing air to the space being conditioned where the volume of the air is always the same, regardless of the heating and cooling requirements.

Cost Payback – An analysis done on building systems where the initial cost of the system and the energy consumption of the system are compared to figure out at what point the energy consumption has saved enough money to pay for the up front initial cost of the system.

Cubic Feet per Minute (CFM) – A measurement of air flow used in HVAC design. It is the volume of a space being moved in a certain amount of time.

Energy Consumption – The amount of energy required to run the heating and cooling system.

Energy Efficiency – A measuring tool for HVAC system which tells how well a HVAC system is heating and cooling. The better the energy efficiency, the less energy is used to heat and cool the space.

Ground Source Heat Pump System (GSHP) – A system where pipes are placed into the earth to be used to take and replenish heat from the ground. The pipes are connected to air handling units in the space, where air is provided to the space for heating and cooling.

Heating, Ventilation, and Air Conditioning (HVAC) – The general term used for describing the methods to provide heat, cool and outside air to a building.

Interior Zones – Spaces in the center of the building typically requiring less heat than the perimeter areas. These spaces can require cooling all year round depending on the amount of people and computers located in these spaces.

LEED - The Leadership in Energy and Environmental Design (LEED) Green Building Rating System™ is the nationally accepted benchmark for the design, construction and operation of high performance green buildings. LEED gives building owners and operators the tools they need to have an immediate and measurable impact on their buildings' performance. LEED promotes a whole-building approach to sustainability by recognizing performance in five key areas of human and environmental health: sustainable site development, water savings, energy efficiency, materials selection and indoor environmental quality.

Office Space – Areas in the building where people work. Typically the spaces are located around the perimeter of the building in a call center.

Perimeter Zones – Spaces around the outer area of the building requiring more heat than the inner areas of the building. These zones typically have the glass loading.

Pressurized Underfloor Plenum – The space below the raised access flooring that is pressurized with supply air by the air handling unit.

Raised Floor – The part of the floor that creates the top portion of the underfloor plenum.

The floor is typically 8" to 18" tall and is supported on metal pedestals.

Return Air – Air that is typically drawn from the upper part of the building or room back to the air handling unit.

Return on Investment – The amount of money saved in the long run by comparing the energy consumed versus the upfront initial cost of a system.

Roof Top Unit (RTU) – A mechanical device used to provide heating and cooling to spaces. These units are typically located on the roof.

Supply Air – Air that has been filtered and conditioned to the required temperature and humidity. The air includes a code required outside air.

Supply Outlets – A method of providing air from the underfloor plenum up to the space being conditioned. These can be manual or powered with a thermostat.

Tempered Air – Air that has been heated or cooled.

Underfloor Air Distribution (UFAD) – The term given to a system where the heated and cooled air is provided to the space from the underfloor plenum space out to the space to be heated or cooled.

Underfloor Plenum – The space in the floor where the air is pushed into by the air handling unit. This space is typically formed by a concrete floor, building walls and raised access flooring.

Variable Air Volume (VAV) – A method of providing air to the space being conditioned where the volume of the air varies based on the actual requirements of heating and cooling.

Variable Air Volume Outlets - A method of providing air to the space being conditioned where the volume of the air varies based on the actual requirements of heating and cooling. The outlets placed in the floor continuously move and adjust to the space load. These outlets are usually serving a room or area (conference room, training room, etc.) that have two or three daisy chained to a thermostat.

Water Column – A unit of pressure that is a measurement determined from two heights of fluid. Usually a base point is established and the measurement height is found. The difference in the two points is a measure of pressure due to the weight of the fluid.

CHAPTER 2. GENERAL SYSTEMS DISCUSSION

DISCUSSION OF GENERAL BACKGROUND LITERATURE

In the past, the design approach for an HVAC system in call centers has been to supply air, both heated and cooled, through ductwork and overhead diffusers. These spaces are broken up into zones of similar occupancies with one thermostat to regulate the entire area. The overhead supply mixes the air in the entire space, which will keep the entire space at the same set point temperature. Occupant fresh air is provided to the space through the air handling unit.

Underfloor Air Distribution Systems are designed to supply conditioned air from under the floor (between the slab and the raised floor). The space between the slab and the raised flooring essentially makes up a large duct. The space is maintained between .05" and .1" of pressure (Water Column – WC) (Sodec and Craig 1991). A fan from a central air handling unit is used to generate the underfloor pressure. Typically, a pressure sensor and control package is used to maintain the static pressure required. Air is supplied to the space ranging from sixty three to sixty eight degrees Fahrenheit. The required supply outlet temperatures need to be supplied at the higher temperatures compared to a standard overhead system to keep the occupants near the floor outlets from being overcooled.

The air handling unit can be heated and cooled in several different ways, some being more efficient than others. The topic of discussion for this paper is to find the efficiency benefits associated with the newer air distribution system. There is a national push to use our resources wisely.

The space between the concrete and the raised floor is typically 12" to 18" tall. The height is determined based on the variable air volume (VAV) box sizes that go under the floor, as well as the electrical cabling and other equipment that needs to be placed under the floor.

In addition to the basic components under the floor, some of the ductwork may be placed under the floor as well. The air serving under the floor needs to be ducted to within fifty to seventy five feet of all the air outlets through the floor. This requirement is due to the heat transfer that occurs as the air travels along the concrete floor. It can (and will) begin to change temperature. To alleviate some of the loss of temperature, and to get the air within the fifty to seventy five feet of the outlets, ductwork needs to be placed in the floor. While traditional ductwork is one option, it is less expensive to use "air dams." Air dams are made up of the concrete floor, the raised floor and sheet metal along the sides of the pedestals, which hold up the raised floor, to create a duct.

The perimeter of the building has special heating and cooling requirements compared to the central space. The outer part of the building has heating and cooling loads that are different than the inner part of the building, mainly from the losses (and gains) through the walls & windows. To accommodate for the losses in this area VAV boxes are placed along the perimeter spaces with outlets approximately twelve inches away from the windows and towards the inner area of the rooms.

Controlling Air Flow

The VAV boxes, ductwork and outlets along the perimeter of the building act as heating in the winter and cooling in the summer. The VAV boxes and the outlets are controlled through the use of a thermostat in the mini zone it controls. In the winter, the boxes provide three stages of heat. In the first stage, the air is drawn in through the outlets toward the center of the building (usually 6' to 10') through the VAV box and then the air is blow up along the outer edge of the building. The second and third stages of heat act similar except the addition of the second stage provides fifty percent of the electric heat from the VAV box and the third stage provides one hundred percent of the electric heat. Typically, the entire cooling load is handled by the central air handling unit. During the cooling mode the outlets act the same as the other outlets by allowing air to freely go into the space. There is an opening on the box which allows the air to pass through, independent of the ductwork.

The air in the central spaces of the building is handled differently as well. This space is made up of large, open areas with a high number of people and computer loads. This can create a need for cooling year round, even in some Northern climates. The air handling unit pressurizes the space allowing air to flow up through the outlets. The temperature in these spaces are controlled either by a thermostat serving small zones through VAV outlets or by passive floor outlets where the occupant has control over their space temperature.

To help control the temperature and humidity levels, the primary cool air is mixed with warm by-passed return air at the air handler to produce supply air at the required temperature and humidity to be delivered to the space for the occupants to feel comfortable. This is the case in both the cooling and heating modes of the UFAD systems.

As with any system, after the air conditions the space it needs to go somewhere. The air that comes up through the floor is returned to the air handling unit as high as possible to keep the air from mixing with the conditioned air. When the ceiling is a lay-in ceiling, the area above the ceiling is typically used as a return air plenum and the air is allowed to flow back to the unit through grilles or openings in special lights. In an area where there is no ceiling, the ductwork is usually exposed and the air is allowed to flow back to the air handling unit through this (Bauman 1996). In addition, the air can then be mixed with the supply air to create a more comfortable space, as mentioned above.

The ventilation air provided to the space is satisfied through the central air handling units. The air either comes in directly through the roof top units, or in the case of air handling units the air is ducted directly to the unit from a louver or roof intake.

ASHRAE has done numerous studies to determine the comfort zones of people occupying spaces. These are published in the ASHRAE Standard 55-1992. These studies look to find the level where people perceive the space as being comfortable. The level of comfort can be skewed. How the air is delivered to the space, the temperature of the air and the humidity in the space, as well as the person's activity level, amount of clothing worn and type of clothing worn are a few factors that can effect perception. ASHRAE studies have determined that the HVAC system is running properly when eighty percent of the occupants are happy (ASHRAE 1989). In another study by Schiller it was determined that forty percent of office workers would prefer to feel either warmer or cooler. Based on studies like these, one can believe that the UFAD system potentially improves not only efficiency, but on how people perceive and actually feel in office space environments. (Schiller 1998)

Under floor air distribution systems are gaining popularity in the Sioux Falls, SD area as well as other parts of the United States due to the benefits the system provides over the standard overhead HVAC systems currently being used. The open areas and the increase of heat generated in the large call center spaces along with the ability to configure space differently as the building occupants change and grow, the UFAD system has continued to gain in popularity (TAC System Guidelines, 1996). In addition to meeting the changing needs of the tenants, the increased awareness of people's health, comfort and productivity levels have kept the HVAC industry searching for ways to improve the systems being designed and installed.

BENEFITS OF UFAD

This section below will describe the benefits associated with using a UFAD system for heating and cooling. The design of several local call centers were reviewed not only for first cost, but ease of installation, owner comfort, air quality, energy consumption, worker satisfaction and productivity, maintenance costs, system flexibility, building adaptability, air quality and building cost payback analysis.

The energy used by this system can be reduced in the way the air is removed from the space. Air is supplied low and returned high. The air is supplied at a higher velocity through smaller sized outlets, mixing the occupied zone (up to 6' above the floor) by allowing air to stratify above this point (EH Price, 2007). The plume of heat given off by the computers and other equipment measuring or placed over six feet is directly taken up through the return grilles to the air handling unit. The heat generated is not mixed throughout the space, thus an energy savings.

Energy can also be saved by using an economizer on the system. The temperature the air is delivered to the space is four to seven degrees warmer than a conventional system. The increased temperature allows the use of "free cooling" more days of the year, thus reducing energy costs.

In call centers, the zones for these spaces are typically large and are seeing the same heat loads. Currently, one thermostat controls the entire zone. With UFAD, there are manually adjustable diffusers located at each person(s) area. This creates smaller zones with a VAV box and thermostat, which can be controlled locally for personal comfort. Not only is this a plus for occupant comfort, this saves the owner energy by reducing the need to run the unit for the entire space loads at a set temperature.

Fan energy saving can be associated with UFAD systems. A recent study shows that UFAD systems save an average of 48% over a conventional VAV system (Webster 2000). The static pressure supplied to the underfloor system is much less than that of a conventional system.

Occupant comfort is one of the large benefits. It has been noted that a person walking continuously around in an office will experience an effective temperature of the environment that is approximately three to five degrees warmer than a person sitting quietly at their desk

(Bauman 2001). With the variation in people's metabolic rate in addition to the clothing preferences, local control of the temperature around the space can increase a person's productivity and attitude toward the work place. This benefit is due to the localized thermostat control for their workspace provided by UFAD systems.

The UFAD system can adapt to the varying changing needs of the building due to growth and industry change. If buildings are reconfigured often or ownership changes this system gives maximum flexibility. A study in 1997 found that the national average churn rate (as defined as the percentage of workers per year and their associated work spaces in a building that are reconfigured or undergo significant changes) to be 44% (Benchmark III 1997). Using the 44% national average turn rate, the savings between conventional overhead systems and UFAD systems in reconfiguring the HVAC and electrical distribution has been estimated at $1.50 to $2.30 per square foot (York 1993, Loftness 1999). VAV boxes along the perimeter of the building, which provide heat, can be moved. In addition, all of the floor outlets can also be changed and relocated. The quantity of floor outlets can be modified as well for spaces that have open areas to heat (i.e. a training room).

Improved air quality is another benefit of this system. Because the air is delivered at the occupant level, the air has not been mixed with all the contaminants already in the room. This provides a cleaner air to the occupant. A laboratory study of floor supply systems has shown that ventilation performance can be improved 20-40% by using the full economizer mode. In addition, a reduction in the age of the air in the breathing zone was shown (Loftness 1999). With the high return and non-mixing of the space, the higher contaminated air is taken out of the space reducing the contaminated air in the space.

While the UFAD system can potentially have higher first cost, the overall energy consumption of the building will be less than a conventional system. The operating costs will be reduced based on the economizer setting and higher temperature supplied to the spaces, as well as being able to downsize some of the larger fan equipment due to lower actual cooling loads.

During the design phase of the building, the architect can reduce the overall floor to ceiling height of the building, thus resulting in the reduction cost of the project. Building heights may be reduced by 5-10%, due to the fact that overhead spaces for ductwork will be reduced because the system utilizes a return air plenum (Knight 1992). The increase in flooring cost may be offset by this reduction in building height.

CHALLENGES OF UFAD

Providing air from under the floor can lead to some challenges. These can include dirt entering the air path, cold feet or drafting, future design issues due to new technology, higher installation costs, condensation problems and relevant codes.

There are some spaces in a building that are a design challenge for UFAD systems. These include, but are not limited to bathrooms, cafeterias, shops, places where water can spill and vestibules. The concerns that the spaces mentioned can potentially contaminate the air by allowing water, food, and other items to enter the duct system and then the contaminated air can spread around the building. Likewise, the underfloor area above the concrete slab needs to be completely cleaned during the flooring phase of construction to eliminate the dust (more so the perceived dust) from debris, sheetrock, dirt and other items from getting into the air stream.

It is believed by some that when air is supplied by their feet it is going to make them cold. Air for underfloor systems is provided usually between sixty-two and sixty-five degrees. The carpet on the floor acts as insulation so cold feet should not be an issue. Nonetheless, people still can perceive the floor as being cold and drafty and can cause concern.

While the UFAD system gains in popularity every day, it is still a relatively new technology. Building owners are learning and asking about the system as more articles are being published and LEED is pushing for greener buildings. Engineers doing the designing the buildings, architects and everyone else in the design process need to be aware of how a UFAD system is to be designed and its benefits. There is currently limited information available to use as a design guide, but ASHRAE has written a book on Underfloor Air Distribution Design and other informative articles are becoming more prevalent (ASHRAE 2003). If care is not taken during the design process, unnecessary costs could be added to the building to implement a UFAD system.

In addition to the potential added design costs because of unfamiliarity of the product, installation costs could increase for the same reason. Contractors that are installing their first UFAD system may not know what or how to install it. The contractor may feel the need to increase the cost of the job because it is a new technology. After the contractor has installed a few systems, they most likely will realize that it is easier to install than a conventional system.

In more humid climates one problem presented is, the outside air must be dehumidified before being delivered to the space. While this is an easily solved problem by using bypass of the conditioned air to mix with the cooled air, the higher cooling coil temperature will decrease the chillers ability to dehumidify some air. Some mixing of the return air with the cooler air may be required, which can decrease some of the energy savings.

CURRENT HVAC STANDARDS

There are three standards from ASHRAE that are related to underfloor air systems directly. The three standards are ANSI/ASHRAE Standard 55-1992, Thermal Environmental Conditions for Human Occupancy, which defines a comfort zone; ANSI/ASHRAE Standard 62-1999; Ventilation for Acceptable Indoor Air Quality, which provides guidelines for ventilation rates; and ANSI/ASHRAE Standard 113-1990, Method of Testing for Room Air Diffusion, which provides a method for evaluation the air diffusion performance. Standard 113-1990 is designed to address overhead conventional systems not new UFAD systems. In addition to the above standards, local building and fire codes need to be considered during the design phase of a project. Code officials limited experience with the above standards and local codes related to UFAD may misinterpret the codes when inspecting underfloor systems (Bauman 2001). In the future, codes will need to address UFAD requirements - separately.

SYSTEM ECONOMICS

Many of the pros and cons for a UFAD system have been discussed above. A recent study by Bauman (1992) found that the perceived higher cost of the UFAD system is the top reason the system is not used more widely. In working directly with building owners and contractors, the system is believed to be more expensive based on the improved comfort, air quality and productivity of the worker. When looking at the economic impact of the system the main considerations, besides the items listed above are first costs, maintenance costs, installation costs, energy consumption, space changeover and lower life cycle costs.

First costs for a UFAD system appear to be slightly more, but not by a large amount when compared to an overhead VAV system. In a conventional system, ductwork goes to each diffuser. The UFAD system utilizes a plenum space with outlets, reducing the ductwork within the system. In many cases the air handling unit will be slightly smaller with a UFAD system over a conventional system.

The life cycle costs of a UFAD system will more than make up for the extra up front costs. Some of the reduction in life cycle costs come from smaller fans in the air handling units (or roof top units), increased thermal comfort for occupants, increased employee satisfaction and production and improved flexibility for moving equipment and people (churn rate), all of which have been discussed in detail above.

The ability to down size the fans for the air handling unit occur both, due to the lowered static pressure of the system and also to the individual occupant zone controls. With the underfloor plenum being pressurized at .1" wc versus the standard 1.5"+/- wc the fan required to provide the pressure is greatly reduced. In addition, the person next to each diffuser, whether manual or VAV, has control over their local space. This can reduce the required air being provided to the space while still making the occupant comfortable.

HEATING AND COOLING PLANT DESCRIPTIONS

The heating and cooling plant to serve the UFAD system are roof top units, boiler and chiller and a ground source heat pump system. Each of the systems have been used for serving under floor air applications, and have been compared against each other for payback analysis on an overhead system, but not reviewed in conjunction with a UFAD system. This comparison is needed to understand the value of the system overall.

RTU

A roof top unit (RTU) heating and cooling plant is usually located on the roof. The unit is self-contained and includes a direct-expansion cooling coil, a direct-fired heater, usually gas or electric, a refrigerant compressor with an air-cooled condenser and fan, a supply fan, an air filter and an economy-cycle outside-air control system with return, relief and outside air dampers. A RTU system typically lasts for 20 years.

Using the RTU in conjunction with the UFAD system, there is supply air ductwork down to under the raised floor and from the return air plenum back to the unit where the heating and cooling takes place. For computing the energy consumption, the full economizer will be used included for free cooling.

Some advantages to the RTU system are very low installed cost, single point of ventilation, outdoor air economizer, self-contained factory packaged controls (although not being used on this system), space pressurization control and good interior aesthetics as well as limited inside space requirements.

Some disadvantages of the RTU system are placing the unit (rigging), roof penetrations, lost floor space, several service points per building depending on the quantity of RTU's used, poor exterior aesthetics, noise, higher energy costs than other systems and difficulty dehumidifying, especially in a UFAD system.

BOILER/CHILLER

A boiler/chiller heating and cooling plant is usually located in a large mechanical room in the building and/or sometimes in a penthouse on the roof of a building. A boiler can produce low, medium or high temperature water. Low temperature water boilers are the most widely used in the light commercial applications, including the UFAD system. Boilers produce hot water through heating the water. The water is heated using a gas, LP, fuel oil or electric burner. Chillers produce cool (or cold) water. They include a compressor, a condenser, an evaporator, and internal piping and controls. Like boilers, there are many different types of chillers that can be utilized. For the UFAD projects being analyzed, and air cooled packaged chiller is being reviewed. A boiler, chiller and air handling unit typically last for 30 years.

When using a boiler/chiller plant, an air handling unit will be required to move the air throughout the building. Typically, there is a large unit or two, located in the mechanical room or penthouse. Located in the air handling unit are a cooling coil and a heating coil. These coils allow the hot or chilled water to run through the air handling unit where the air is tempered and usually mixed with some sort of outside air and then blown out to the space being heated or cooled.

Like the RTU, with a UFAD system the supply air ductwork goes from the air handling unit down to under the raised floor and from the return air plenum back to the unit where the heating and cooling take place. This system requires a duct from a louver located on the outside wall to the air handling unit to provide fresh air to the building. For the UFAD systems, the outside air duct is sized at fifty percent, which allows for free cooling in the fall and spring.

The boiler/chiller system has many advantages. Some of the advantages are low to moderate operating costs, long life expectancy, quiet operation, easier to run piping than ducts, versatile, good exterior and interior aesthetics and central system control.

Some disadvantages of the system include higher first costs, ventilation ducting, condensate drains, and many points for maintenance and no back-up during equipment failure.

GSHP

The ground source heat pump (GSHP) is the third system being reviewed in conjunction with the UFAD system. A GSHP system is comprised of a ground loop, a heat pump and a heat/cool distribution system. These systems typically last for 25 years for the indoor equipment and the well field should last as long as the building is standing.

The ground loop is comprised of lengths of pipe buried in the ground, either in a bore hole, a horizontal trench or directional bore. The pipe is a closed circuit and is filled with a mixture of water and propylene glycol that is pumped around the pipe absorbing / dumping heat into the ground.

The heat pump, located in the building, extracts (in heating mode) from the ground and uses it to heat (and is the reverse in the summer). The evaporator absorbs the heat using the liquid in the ground loop, the compressor moves the refrigerant around the heat pump and compresses the gaseous refrigerant to the temperature needed for the heat distribution circuit and the condenser gives up heat to the space.

When using a GSHP, the indoor heat pump will move the air throughout the building. There can be several small units, but one or two large units located in the mechanical room or penthouse is the preferred method of moving the air. The heat pumps through the refrigeration cycle heat and cool the space under the floor. Ductwork is required to go from the air heat pump units down to under the raised floor and from the return air plenum back to the unit where the heating and cooling take place. This system requires a duct from a louver located on the outside wall to each heat pump to provide fresh air to the building.

There are many advantages to using a GSHP system. Some of the advantages are low operating cost, high comfort, and simplicity, low maintenance, no outside equipment, good aesthetics and central controls.

Some disadvantages of the system are high first cost, requires expertise to install, condensate piping, many points of maintenance and no economizer mode.

SUMMARY OF PERTINENT RESEARCH

An underfloor air distribution system has many ways to improve today's traditional systems. Many of the methods enable energy savings which can reduce the cost to run the systems. There are some limitations of the system that have reduced the growth of this type of system, but overall, the trend is to use a UFAD system for not only the potential energy savings, but also the increase productivity and happiness of the occupant.

With proper system design, a UFAD can increase the hours of an outside-air economizer, down size the fan design need due to reduced static pressure, improve occupant comfort and productivity and improve indoor air quality, as well as improving overall operating costs of the system.

CONCLUSIONS OF THE LITERATURE REVIEW

While the system components, costs, pros and cons of an underfloor air distribution system have been reviewed above, there are many ways to provide air to the underfloor system. Through past research, it has been shown that UFAD saves the owner money in operating costs, employee productivity and owner churns (Benchmark III 1997).

In the upcoming sections, three specific ways of provide air to the UFAD system will be explored. The costs of the UFAD system will be held constant, assuming the UFAD flooring, ductwork, floor diffusers, etc. will remain the same for each of the three systems, but the type of air handler and method of producing the heating and cooling air will be varied. These three systems will be evaluated for energy savings and upfront costs to see which method will provide the owner with an even greater rate of return.

CHAPTER 3. PROJECT IMPLEMENTATION

REVIEW OF PROJECT ACTIVITIES AND GOALS

The purpose of the project is to determine what type of system is the best for an owner in terms of energy consumption and cost. While it has been shown that UFAD systems are energy saving systems, (Bauman 2003) there are many ways to provide the air to the underfloor system. The air being provided to the plenum space needs to be conditioned. In our market, there have been many ways explored as to how the air should be provided to the plenum space. Three ways that are being compared in the project are roof top units, a boiler/chiller system with an air handling unit, and a ground source heat pump system. These three methods of providing air are being coupled with the UFAD system.

With the systems listed above, the initial cost for a building can and will be calculated. In addition, the energy consumption will be reviewed for each type of system. From the initial cost and operating cost, simple paybacks will be calculated.

The information that is found in the above calculations will be used to help the owners of the call center / office buildings to determine the type of system that is right for their company. In addition, they will be able to have a calculated estimate for how much money they will be spending.

DESCRIPTION OF PROJECT IMPLEMENTATION

The project is based on several large call centers that have been designed and built within the last three years. Additionally, one project will be utilized for the energy consumption calculations. The heating and cooling loads will be calculated for a 162,000 square foot call center. The total heating, cooling, peak heating, peak cooling, outside air cubic feet per minute (CFM) and building CFM will be calculated. Data has been collected from several firms in the area for both equipment and installation costs. Local energy companies as well as the US Energy statistics from the US government have been contacted for average fuel costs, both electric and gas.

METHOD OF COLLECTING DATA

The first part of the project required the heating and cooling loads for a building. This was done using Carrier's Heating Analysis Program (HAP) V4.34 (Carrier 2007). The building architectural drawings were obtained. From the architect's drawings, the building was entered into the HAP program one room at a time. The entries include general floor and building areas, lighting, equipment, walls, windows, doors, roofs, infiltration, people and any miscellaneous loads. In addition, the program has system inputs. In this case, most of the inputs are left as default values and the system has been left as undefined, because the program is not designed to analyze systems. Samples of the inputs for the call center, room by room and the system inputs have been included in appendix A. In addition to the building room inputs, the wall and roof construction have been entered into the program detailing the composite R-values for each part of the wall and roof construction. The city of design has been entered (in this case, Sioux Falls, SD), and schedules have been built for equipment, lights, people, and on/off operation of the thermostat within the building. Samples of the schedules have been included in appendix B. With all the data input into the computer for the spaces, the total building heat loss and gains as well as the peak heat loss and gains can be calculated. Samples of the building heat loss and gains for the call center being utilized as a model have been included in appendix C and samples of the energy utilization reports have been included in appendix D. Now that the building has been modeled, the energy costs need to be determined.

To determine the energy costs for the area, both the local gas company and electric company, as well as the US Government, Energy Information Administration has provided rates. These rates were used for the estimate of energy costs described later. The rate sheets for this information are included in Appendix F.

In order to get a simple cost payback, the upfront cost of the system needed to be determined. The design of the model call center was done utilizing a UFAD system. After the UFAD system was drawn, two suppliers were asked to give budget pricing on the air distribution systems utilizing the three methods that were being compared. (O'Connor 2007, Climate Systems 2007). In addition, the mechanical contractor that was installing the equipment gave a budget price for installing the different pieces of equipment, components and ductwork. (Baete-Forseth 2007). The last item required for determining the initial upfront system cost is the well field for the ground source heat pump system. Samples of the energy consumption as well as the peak heating and cooling and well field design for the modeled building have been included in Appendix E. Ground Loop Design software was utilized for the calculation (Thermal Dynamics Inc. 2006). The inputs for the software were calculated and used from the HAP program (Carrier 2007). With these items, the initial upfront cost of the system was determined.

The next phase of the project uses the calculated costs to determine a cost payback analysis for the systems compared to each other.

METHOD OF ANALYZING DATA

The data was analyzed using a couple of different methods. The initial estimates were entered into a computer program written by the government. The program is called eQUEST 3-6. While the program is very thorough, it was felt to be too complex for the needs of the simple payback of a system for giving information to the owner. In addition, the complexity of the program left room for errors as the author of this paper was not sure where all the calculations were coming from. Therefore, a simple spreadsheet was designed that allows for easy and quick calculation for determining a simple payback between systems.

The spreadsheet was written to make inputs easy. The suppliers and contractors that provided budget numbers are entered into the spreadsheet. Since budget numbers were obtained from two different suppliers, the average cost of the equipment was used. An average cost was calculated using the RTU's, boiler / chiller, and Ground Source Heat Pump options. All options have the UFAD system added to the cost since that part of the project will not change.

After the average cost of the equipment has been determined, the total heating and cooling BTU's are input into the spreadsheet. This has been determined using the HAP program as described above. In addition to the total BTU's, the cost of all the energy is input into the spreadsheet. All these input numbers are adjustable.

After the inputs are in place, the equipment is entered into the system. The three systems being compared are input with the formulas to update the total energy consumption of the gas and electricity. The efficiencies and COP's may be changed to the type of equipment being utilized. The initial cost of the building as well as the annual energy consumption is calculated. In addition, four systems are included on the spreadsheet for comparison reasons. The paybacks of the systems versus each other are then calculated at the bottom of the spreadsheet. These numbers can then be used to determine with a building owner what the initial cost of there system and operating costs may be.

LIMITATION OF THE IMPLEMENTATION PLAN

There are two large limitations to the implementation plan. The first limitation is the amount of software required to run the analysis. It takes at least three programs and a spreadsheet. In addition, the numbers calculated by the spreadsheet are only accurate numbers if the suppliers and mechanical contractor are providing accurate budget pricing. If the cost of the equipment is skewed, the results will be as well.

As the project progresses, the building may change slightly. With the large amount of data, it takes quite a while for any changes to be changed in all the different input areas. A program such as eQUEST could make the changes easier, but without knowing the program real well, the input data could have errors leading to the wrong outputs.

CHAPTER 4. RESULTS AND DISCUSSIONS

DISPLAY AND ANALYSIS OF THE DATA

The data collected was done largely through emails and phone calls with local Sioux Falls, SD suppliers (O'Connor 2007, Climate Systems 2007) and with a local mechanical contractor (Baete-Forseth 2007) located in Sioux Falls, SD. The numbers collected from the contractor and suppliers were entered into the spreadsheet. The call center that was modeled was used for the pricing. The building is 162,000 square feet, has a heat load of 5,600 MBH, a cooling load of 335.1 tons and an estimated CFM for the building of 143,800 CFM. Each supplier was asked to provide budget pricing for average equipment based on a 100,000 square foot building and then the costs were adjusted for the building size and numbers of the project. For the RTU's the equipment bid was 88% for heating and electric cooling. For the boiler 88% was used for heating efficiency, and an IPLV of 14.9 was used for the chiller. Lastly, for the GSHP equipment, in heating mode a COP of 3.5 was used and in cooling an EER of 16.0 was used. Each supplier submitted estimated costs for the equipment efficiencies listed above. The O'Connor Group was \$310,000 for the RTU's, \$420,000 for the boiler & chiller system, and \$310,000 for the GSHP equipment. Climate Systems, Inc. was \$320,000 for the RTU's, \$400,000 for the boiler & chiller system, and \$268,500 for the GSHP equipment. Summary of the equipment and installation costs are shown in table 1 below.

O'Connor Group	Cost / SF	Installed Cost / SF
RTU	\$3.10	\$5.58
B/C	\$4.20	\$7.56

GSHP	$7.50	$13.50
UFAD	$2.30	$4.14

Climate Systems	Cost / SF	Installed Cost / SF
RTU	$3.20	$5.76
B/C	$4.00	$7.20
GSHP	$7.09	$12.75
UFAD	$1.63	$2.94

	System Cost Company A / SF	System Cost Company B / SF
RTU	$9.72	$8.70
B/C	$11.70	$10.14
GSHP	$17.64	$15.69

Table 1

After the equipment costs were obtained, the numbers were converted into a cost per square foot per system. The cost per square foot was also determined for the UFAD system as well. In addition, an "install factor" was placed into the cost per square foot of each system. This was done by contacting Baete-Forseth, a local Sioux Falls, SD mechanical contractor that has installed several systems. It was determined that in the complete cost of these systems, it is approximately fifty-five percent equipment cost and forty-five percent of labor. Therefore, the cost per square foot installed cost includes the labor factor. After the cost per square foot was determined per type of system the average installed cost per system was calculated. This was done by adding the cost of the UFAD system to the suppliers cost and then averaging the installed cost per system. It was found that for the RTU system the average installed cost was $9.21 per square foot. For the boiler & chiller system the average installed cost was $10.92 per square foot. For the GSHP system, the average installed cost was $16.67 per square foot. These numbers are shown below as average system first cost per square foot in table 2.

The electrical and gas rates were obtained by utilizing the rate sheets from the respective local companies (Xcel Energy 2007, MidAmerican Energy, US Government 2007). The gas, liquid petroleum, fuel oil, and electricity rates were entered into the spreadsheet. The rates used were $1.80 per therm for natural gas and $0.06 per KW hour electrically for calculating energy costs. To get all the information on an equal cost basis, two energy conversion numbers were required. For the cost analysis, one KW is equal to 3,412 BTU's and one therm of natural gas is equal to 100,000 BTU.

The HVAC loads and energy reports were all obtained by putting inputs into the HAP program and GAIA Geothermal (Carrier 2007, GAIA Geothermal 2007) heat pump program as described above. The HAP program is a heating and cooling load estimation program that determines the required heating and cooling BTU's required per year. This program can be used in any city in the United States (and abroad) and does the calculations based on wall, window, door and ceiling R-values as well as scheduled inputs for equipment, lights and people. While this input can and is tedious, samples of the input and output reports are shown in the appendices, and full input / output pages are kept on file at Innovative Engineering Solutions, LLC corporate building located at 26784 Country Acre Dr., Sioux Falls, SD. The full reports can be obtained by writing to the address provided above. For the building parameters of this project, which were described above, the total heating BTU's required for the year are 882,567,000 and the total cooling BTU's required per year are 3,378,156,000.

Now that the information has been gathered, the electric and gas consumption per year per system can be calculated. The electric consumption for the RTU is 989,791, for the boiler and chiller system is 478,829 and for the GSHP system is 142,618. Likewise, the gas consumption can be calculated. For the RTU and boiler chiller system it is 10,030 therms and no gas is used with the GSHP system. The difference in electric consumption from the systems is due to the efficiencies of the equipment.

The spreadsheet calculates a simple cost payback analysis. This spreadsheet provides all potential inputs (can be changed) in light yellow. The rest of the spreadsheet will update automatically. This will allow the user to enter in information and get a real time update as to the energy payback of the system as well as the cost of the system based on square footage of the building. For our systems, the initial cost is calculated using the installed cost per square foot of the system and the square footage of the building entered. In this case, 162,000 square feet. This gives the initial cost of each of our systems; RTU - $1,492,049, boiler / chiller system - $1,769,069 and GSHP - $2,700,002. In addition to our initial cost, the energy cost per year is calculated. This is done by utilizing the electric and gas rates with the total energy consumption and equipment efficiencies. The energy cost per year for the RTU is $77,440, the boiler / chiller system is $46,783 and the GSHP is $8,557 per year.

Now that the initial cost and energy cost have been calculated, the paybacks for each system can be calculated. When comparing the RTU to the boiler and chiller system, the payback is 9 years, comparing the RTU to GSHP system the payback 17.4 years, and comparing the boiler and chiller system to the GSHP system the payback is 24 years.

The information described above is shown in a summary format in table 2 below.

Project:	First Premier Bank
Date:	12/5/2007
Designer:	JRG

Building Info Summary		
SF	162,000	
Heat	5,600	MBH
Cool	335.1	Tons
CFM	143800	CFM

Avg. System First Cost / SF		
RTU	$9.21	
B/C	$10.92	
GSHP	$16.67	
Total BTU's Heating	882,567,000	BTU
Total BTU's Cooling	3,378,156,000	BTU
Cost of Electricity	$0.0600	per KWH
Cost of Nat. Gas	$1.80	per Therm

1 Kilowatt-hour	3,412	BTU
1 Therm(ccf) Nat Gas	100,000	BTU

System	COP / Efficiency / IPLV	Energy		Cost Per Unit	Total Cost / Year
Heat Pump Heating	3.6	71,851.6	kWh	$0.0600	$4,311
Heat Pump Cooling	18.0	61,116.1	kWh	$0.0600	$3,667
Boiler Heating	88.0%	10,029.2	Therm	$1.8000	$18,053
Chiller Cooling	14.9	478,829.2	kWh	$0.0600	$28,730
RTU Heating	88.0%	10,029.2	Therm	$1.8000	$18,053
RTU Cooling	100.0%	990,080.9	kWh	$0.0600	$59,405

System Type	Electric Consumption (kWh)	Gas Consumption (Therm)
88% RTU	990,080.9	10,029.2
B/C	478,829.2	10,029.2
GSHP	132,967.7	0

System Type	Initial Cost	Energy Cost / Year
88% RTU	$1,492,049	$77,457.36
Boiler / Chiller	$1,769,069	$46,782.26
GSHP	$2,700,002	$7,978.06

Simple Payback		
RTU vs. B/C	9.0	Years
RTU vs. GSHP	17.4	Years
B/C vs. GSHP	24.0	Years

Table 2

SUMMARY OF RESULTS

Based on the information collected and described above, when entering the information into the spreadsheet, the initial cost of the ground source heat pump was the most expensive. The cost per square foot for the inside equipment for the ground source heat pump was not higher than the other systems, but when the cost of the well field was added into the equation the cost rose dramatically. The boiler / chiller and the RTU were similar in cost, with the boiler / chiller being about $300,000 more expensive. The energy consumption of the roof top unit was $77,439 per year with the boiler / chiller using $46,783 per year. The GSHP system was really energy efficient. The cost to run the GSHP system was approximately $8,557 per year. While the large difference in energy consumption, the upfront cost of the system makes the paybacks fairly large, as noted above.

CHAPTER 5. CONCLUSIONS

INTERPRETATIONS OF THE FINDINGS & CONCLUSIONS

The buildings and systems compared were specifically for a call center application. While the results could likely be used for other building types, the high heat load due to the high people loading, high ventilation rates and equipment in the space likely limits the results to the call center type building.

It was interesting to see the comparisons of this equipment side by side. While these systems are compared regularly, they are not compared for under floor air distribution systems.

With the high cost of the ground source heat pump system, it makes it hard to use the system due to the large time frame for payback. However, if the owner is planning on being in the building long term, it may make sense because once the well field is installed and paid for; the equipment cost to replace was similar to the other systems reviewed.

It is believed that the well field cost became very large due to the unbalance heating and cooling load for the building. The call center requires a large amount of cooling due to the people and equipment load in the building.

When comparing the rooftop unit versus the boiler / chiller system, as anticipated the initial cost of the boiler / chiller system was more expensive (16% more for the boiler / chiller system) and the RTU required more energy to run the system (40% more to run the RTU system). Regardless of the initial cost and energy consumption, the controllability of the boiler / chiller system and the comfort provided by the system make it a nice choice for combination with a UFAD system.

The roof top unit compared to the ground source heat pumps is very inexpensive but costly to run (GSHP has 45% more initial cost and 89% less energy to run). The payback between these systems is higher than anticipated, but with the controllability of the heat pump system and low energy cost this system would be a possible choice for a call center owner.

The boiler / chiller system versus the ground source heat pump system is a similar comparison to the rooftop unit versus ground source heat pumps (GSHP has 34% more initial cost and 82% less energy to run). The payback is higher than anticipated. Both systems have good controllability, but the GSHP system has a much lower energy cost per year.

RECOMMENDATIONS

When call center building owners are looking at using different systems for UFAD, care must be taken due to the large people and equipment load in the building. These buildings need cooling, sometimes year round, and the GSHP doesn't necessarily work well because of the unbalanced loads.

Nonetheless, if the owner is looking for the most energy efficient building and doesn't mind the upfront cost, a GSHP system can be a great way to go. The system is very controllable, can provide the heating and cooling required and will give the owner a very low cost per year to run.

If the owner is not up for the upfront cost of a GSHP, they may want to look at using a boiler / chiller system. This system is more controllable than a roof top unit system and is similar in cost per year to run.

RECOMMENDATIONS FOR FURTHER RESEARCH AND EVALUATION

There are three recommendations for further research. The first recommendation is to look at a software package such as eQUEST further. While the software was reviewed for this paper, it was not reviewed or used due to the complexity and ease of use issues. Much more time and comparison to the spreadsheet where the actual calculations are known need to happen before third part software would be used.

Secondly, due to the nature of the call center buildings where they are cooling dominate, a hybrid heat pump system should be evaluated. This could be as simple as adding a cooling tower to the system, where the well field could potentially be cut in half, reducing the initial cost of the system while maintaining a low cost energy solution.

Thirdly, a larger survey could be taken for the estimated costs of the equipment and installation. Due to the relatively new nature of the UFAD system in this area, only a few jobs have been completed utilizing the system. As the popularity of the system grows, more contractors will be installing it and a larger sample population will be able to be obtained for cost estimating purposes.

APPENDIX A. SAMPLE ROOM AND SYSTEM INPUTS

This is the data entered into the Carrier Heating Analysis Program (HAP). It includes floor area, ceiling height, building weight, ventilation requirements, heat generated by people loads and equipment loads, walls, windows, doors, ceiling, and infiltration.

These items are entered for each room to determine a heating and cooling load for calculating air flow rates for each room / area.

Space Input Data

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Innovative Engineering Solutions

04/19/2008
07:12AM

1R C M Room

1. General Details:

Floor Area	95.0	ft²
Avg. Ceiling Height	10.0	ft
Building Weight	70.0	lb/ft²

1.1. OA Ventilation Requirements:

Space Usage	User-Defined	
OA Requirement 1	9.0	CFM
OA Requirement 2	0.00	CFM/ft²
Space Usage Defaults	ASHRAE Std 62-2001	

2. Internals:

2.1. Overhead Lighting:

Fixture Type	Recessed (Unvented)	
Wattage	1.50	W/ft²
Ballast Multiplier	1.08	
Schedule	Lights	

2.2. Task Lighting:

Wattage	0.00	W/ft²
Schedule	None	

2.3. Electrical Equipment:

Wattage	0.00	W/ft²
Schedule	None	

2.4. People:

Occupancy	0.5	Person
Activity Level	Sedentary Work	
Sensible	280.0	BTU/hr/person
Latent	270.0	BTU/hr/person
Schedule	People	

2.5. Miscellaneous Loads:

Sensible	0	BTU/hr
Schedule	None	
Latent	0	BTU/hr
Schedule	None	

3. Walls, Windows, Doors:
(No Wall, Window, Door data).

4. Roofs, Skylights:
(No Roof or Skylight data).

5. Infiltration:

Design Cooling	0.00	CFM
Design Heating	0.00	CFM
Energy Analysis	0.00	CFM

Infiltration occurs only when the fan is off.

6. Floors:

Type	Slab Floor On Grade	
Floor Area	95.0	ft²
Total Floor U-Value	0.100	BTU/(hr-ft²-°F)
Exposed Perimeter	0.0	ft
Edge Insulation R-Value	10.00	(hr-ft²-°F)/BTU

7. Partitions:
(No partition data).

Wall Constructions

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07:12AM

Wall Assembly

Wall Details

Outside Surface Color .... **Dark**
Absorptivity **0.900**
Overall U-Value .... **0.047** BTU/(hr-ft²-°F)

Wall Layers Details (Inside to Outside)

Layers	Thickness in	Density lb/ft³	Specific Ht. BTU / (lb - °F)	R-Value (hr-ft²-°F)/BTU	Weight lb/ft²
Inside surface resistance	0.000	0.0	0.00	0.68500	0.0
Gypsum board	0.625	50.0	0.26	0.56000	2.6
R-13 batt insulation	4.000	0.5	0.20	12.82051	0.2
8-in LW concrete	8.000	40.0	0.20	6.66667	26.7
Outside surface resistance	0.000	0.0	0.00	0.33300	0.0
Totals	**12.625**	**-**		**21.06518**	**29.4**

Roof Constructions

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Built-up Roof + R-7 Board + Steel Deck

Roof Details

Outside Surface Color .... **Dark**
Absorptivity **0.900**
Overall U-Value .... **0.034** BTU/(hr-ft²-°F)

Roof Layers Details (Inside to Outside)

Layers	Thickness in	Density lb/ft³	Specific Ht. BTU / (lb - °F)	R-Value (hr-ft²-°F)/BTU	Weight lb/ft²
Inside surface resistance	0.000	0.0	0.00	0.68500	0.0
22 gage steel deck	0.034	489.0	0.12	0.00011	1.4
R-7 board insulation	4.000	2.0	0.22	27.77778	0.7
Built-up roofing	0.375	70.0	0.35	0.33245	2.2
Outside surface resistance	0.000	0.0	0.00	0.33300	0.0
Totals	**4.409**	-		**29.12833**	**4.2**

Window Constructions

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1'8"W x 13'H

Window Details:

Detailed Input .... **Yes**
Height .... **13.00** ft
Width .... **1.67** ft
Frame Type .... **Aluminum without thermal breaks**
Internal Shade Type .... **None**
Overall U-Value .... **0.625** BTU/(hr-ft²-°F)
Overall Shade Coefficient **0.591**

Glass Details:

Gap Type .... **1/2" Air Space**

Glazing	Glass Type	Transmissivity	Reflectivity	Absorptivity
Outer Glazing	1/4" gray tint	0.479	0.062	0.459
Glazing #2	1/4" clear low-e	0.639	0.116	0.245
Glazing #3	not used	1.000	0.000	0.000

11'8"W x 8'4"H

Window Details:

Detailed Input .... **Yes**
Height .... **8.33** ft
Width .... **11.67** ft
Frame Type .... **Aluminum without thermal breaks**
Internal Shade Type .... **None**
Overall U-Value .... **0.596** BTU/(hr-ft²-°F)
Overall Shade Coefficient **0.591**

Glass Details:

Gap Type .... **1/2" Air Space**

Glazing	Glass Type	Transmissivity	Reflectivity	Absorptivity
Outer Glazing	1/4" gray tint	0.479	0.062	0.459
Glazing #2	1/4" clear low-e	0.639	0.116	0.245
Glazing #3	not used	1.000	0.000	0.000

12'W x 5'H

Window Details:

Detailed Input .... **Yes**
Height .... **5.00** ft
Width .... **12.00** ft
Frame Type .... **Aluminum without thermal breaks**
Internal Shade Type .... **None**
Overall U-Value .... **0.601** BTU/(hr-ft²-°F)
Overall Shade Coefficient **0.591**

Glass Details:

Gap Type .... **1/2" Air Space**

Glazing	Glass Type	Transmissivity	Reflectivity	Absorptivity
Outer Glazing	1/4" gray tint	0.479	0.062	0.459
Glazing #2	1/4" clear low-e	0.639	0.116	0.245
Glazing #3	not used	1.000	0.000	0.000

Door Constructions

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04/19/2008
07:18AM

80 SF OHD

Door Details:

Gross Area	**80.0**	ft²
Door U-Value	**0.300**	BTU/(hr-ft²-°F)

Glass Details:

Glass Area	**0.0**	ft²
Glass U-Value	**0.580**	BTU/(hr-ft²-°F)
Glass Shade Coefficient	**0.880**	
Glass Shaded All Day?	**No**	

Door Assembly

Door Details:

Gross Area	**24.0**	ft²
Door U-Value	**0.300**	BTU/(hr-ft²-°F)

Glass Details:

Glass Area	**20.0**	ft²
Glass U-Value	**0.580**	BTU/(hr-ft²-°F)
Glass Shade Coefficient	**0.880**	
Glass Shaded All Day?	**No**	

APPENDIX B. SAMPLE SCHEDULES

This is the data that is input into HAP program that makes up the people, lights, equipment and occupancy times.

Schedule Input Data

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People (Fractional)

Hourly Profiles:

1:Profile One

Hour	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Value	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

2:Profile Two

Hour	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Value	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

3:Profile Three

Hour	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Value	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

4:Profile Four

Hour	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Value	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Assignments:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Design	1	1	1	1	1	1	1	1	1	1	1	1
Monday	2	2	2	2	2	2	2	2	2	2	2	2
Tuesday	2	2	2	2	2	2	2	2	2	2	2	2
Wednesday	2	2	2	2	2	2	2	2	2	2	2	2
Thursday	2	2	2	2	2	2	2	2	2	2	2	2
Friday	2	2	2	2	2	2	2	2	2	2	2	2
Saturday	3	3	3	3	3	3	3	3	3	3	3	3
Sunday	4	4	4	4	4	4	4	4	4	4	4	4
Holiday	4	4	4	4	4	4	4	4	4	4	4	4

T-Stat (Fan / Thermostat)

Hourly Profiles:

1:Profile One

Hour	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Value	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O

2:Profile Two

Hour	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Value	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O

3:Profile Three

Hour	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Value	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O

4:Profile Four

Hour	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Value	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O

O = Occupied; U = Unoccupied

Assignments:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Design	1	1	1	1	1	1	1	1	1	1	1	1
Monday	2	2	2	2	2	2	2	2	2	2	2	2
Tuesday	2	2	2	2	2	2	2	2	2	2	2	2
Wednesday	2	2	2	2	2	2	2	2	2	2	2	2
Thursday	2	2	2	2	2	2	2	2	2	2	2	2
Friday	2	2	2	2	2	2	2	2	2	2	2	2
Saturday	3	3	3	3	3	3	3	3	3	3	3	3
Sunday	4	4	4	4	4	4	4	4	4	4	4	4
Holiday	4	4	4	4	4	4	4	4	4	4	4	4

Schedule Input Data

First Premier Bankcard Paper 04/19/2008
Innovative Engineering Solutions 07:19AM

Equipment (Fractional)

Hourly Profiles:

1:Profile One

Hour	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Value	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

2:Profile Two

Hour	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Value	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

3:Profile Three

Hour	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Value	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

4:Profile Four

Hour	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Value	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Assignments:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Design	1	1	1	1	1	1	1	1	1	1	1	1
Monday	2	2	2	2	2	2	2	2	2	2	2	2
Tuesday	2	2	2	2	2	2	2	2	2	2	2	2
Wednesday	2	2	2	2	2	2	2	2	2	2	2	2
Thursday	2	2	2	2	2	2	2	2	2	2	2	2
Friday	2	2	2	2	2	2	2	2	2	2	2	2
Saturday	3	3	3	3	3	3	3	3	3	3	3	3
Sunday	4	4	4	4	4	4	4	4	4	4	4	4
Holiday	4	4	4	4	4	4	4	4	4	4	4	4

Lights (Fractional)

Hourly Profiles:

1:Profile One

Hour	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Value	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

2:Profile Two

Hour	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Value	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

3:Profile Three

Hour	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Value	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

4:Profile Four

Hour	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Value	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Assignments:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Design	1	1	1	1	1	1	1	1	1	1	1	1
Monday	2	2	2	2	2	2	2	2	2	2	2	2
Tuesday	2	2	2	2	2	2	2	2	2	2	2	2
Wednesday	2	2	2	2	2	2	2	2	2	2	2	2
Thursday	2	2	2	2	2	2	2	2	2	2	2	2
Friday	2	2	2	2	2	2	2	2	2	2	2	2
Saturday	3	3	3	3	3	3	3	3	3	3	3	3
Sunday	4	4	4	4	4	4	4	4	4	4	4	4
Holiday	4	4	4	4	4	4	4	4	4	4	4	4

APPENDIX C. SAMPLE HEATING AND COOLING LOAD CALCULATIONS

This is the output data after all the inputs have been entered into the HAP program. This includes outputs for sensible cooling, time of day that the cooling load occurs (peak), air flow per space required, heating requirements of the space, floor area and cfm per square foot.

Air System Sizing Summary for Lower 1

Project Name: First Premier Bankcard Paper
Prepared by: Innovative Engineering Solutions

04/19/2008
07:20AM

Air System Information

Air System Name	Lower 1		Number of zones	1	
Equipment Class	UNDEF		Floor Area	53236.0	ft²
Air System Type	SZCAV		Location	Sioux Falls, South Dakota	

Sizing Calculation Information

Zone and Space Sizing Method:

Zone CFM	Sum of space airflow rates	Calculation Months	Jan to Dec
Space CFM	Individual peak space loads	Sizing Data	Calculated

Central Cooling Coil Sizing Data

Total coil load	102.1	Tons	Load occurs at	Jul 1400	
Total coil load	1225.7	MBH	OA DB / WB	93.3 / 72.8	°F
Sensible coil load	960.8	MBH	Entering DB / WB	82.0 / 68.2	°F
Coil CFM at Jul 1400	43555	CFM	Leaving DB / WB	60.5 / 59.2	°F
Max block CFM	43555	CFM	Coil ADP	58.1	°F
Sum of peak zone CFM	43555	CFM	Bypass Factor	0.100	
Sensible heat ratio	0.784		Resulting RH	56	%
ft²/Ton	521.2		Design supply temp.	58.0	°F
BTU/(hr-ft²)	23.0		Zone T-stat Check	1 of 1	OK
Water flow @ 10.0 °F rise	245.28	gpm	Max zone temperature deviation	0.0	°F

Central Heating Coil Sizing Data

Max coil load	1349.2	MBH	Load occurs at	Des Htg	
Coil CFM at Des Htg	43555	CFM	BTU/(hr-ft²)	25.3	
Max coil CFM	43555	CFM	Ent. DB / Lvg DB	44.4 / 74.6	°F
Water flow @ 20.0 °F drop	134.99	gpm			

Supply Fan Sizing Data

Actual max CFM	43555	CFM	Fan motor BHP	0.00	BHP
Standard CFM	41355	CFM	Fan motor kW	0.00	kW
Actual max CFM/ft²	0.82	CFM/ft²	Fan static	0.00	in wg

Outdoor Ventilation Air Data

Design airflow CFM	12876	CFM	CFM/person	16.27	CFM/person
CFM/ft²	0.24	CFM/ft²			

Zone Sizing Summary for Lower 1

Project Name: First Premier Bankcard Paper 04/19/2008
Prepared by: Innovative Engineering Solutions 07:20AM

Air System Information

Air System Name ..... **Lower 1**
Equipment Class ..... **UNDEF**
Air System Type ..... **SZCAV**

Number of zones **1**
Floor Area ..... **53236.0** ft²
Location ..... **Sioux Falls, South Dakota**

Sizing Calculation Information

Zone and Space Sizing Method:

Zone CFM ..... **Sum of space airflow rates**
Space CFM ..... **Individual peak space loads**

Calculation Months ..... **Jan to Dec**
Sizing Data ..... **Calculated**

Zone Sizing Data

Zone Name	Maximum Cooling Sensible (MBH)	Design Air Flow (CFM)	Minimum Air Flow (CFM)	Time of Peak Load	Maximum Heating Load (MBH)	Zone Floor Area (ft²)	Zone CFM/ft²
Zone 1	745.7	43555	43555	Aug 1500	204.1	53236.0	0.82

Zone Terminal Sizing Data

No Zone Terminal Sizing Data required for this system.

Space Loads and Airflows

Zone Name / Space Name	Mult.	Cooling Sensible (MBH)	Time of Load	Air Flow (CFM)	Heating Load (MBH)	Floor Area (ft²)	Space CFM/ft²
Zone 1							
1R C M Room	1	0.7	Jan 2300	38	0.0	95.0	0.40
1R C M Tlt	1	2.0	Jan 2300	113	0.0	355.0	0.32
1R C Supply	1	0.4	Jan 2300	26	0.0	81.0	0.32
1R C W Tlt	1	2.0	Jan 2300	113	0.0	355.0	0.32
1R Center Corridor	1	10.1	Jan 2300	582	0.0	1835.0	0.32
1R Center Elec	1	0.7	Jan 2300	39	0.0	124.0	0.32
1R Center Elev	1	0.3	Jan 2300	15	0.0	48.0	0.32
1R Center Elev Equip	1	0.3	Jan 2300	17	0.0	54.0	0.32
1R Conf (BY HUDDLE)	1	4.3	Jan 2300	248	0.0	220.0	1.13
1R Conf (BY STAG)	1	5.2	Jan 2300	298	0.0	268.0	1.11
1R Conf 2	1	6.2	Aug 2100	357	1.5	306.0	1.17
1R DATA SERVER	1	11.1	Jan 2300	639	0.0	1966.0	0.33
1R Dining / Kitchen	1	107.4	Sep 1500	6158	49.0	3625.0	1.70
1R Dish / Clean-up	1	10.6	Jan 2300	606	0.0	392.0	1.55
1R DTEST / STAGING	1	2.8	Jan 2300	163	0.0	462.0	0.35
1R East Elev Equip	1	0.4	Jan 2300	24	0.0	75.0	0.32
1R East Elevator	1	0.3	Jan 2300	15	0.0	48.0	0.32
1R EAST STAIR	1	4.3	Jul 1000	245	3.9	219.0	1.12
1R East Vest	1	7.8	Jul 0900	445	6.7	100.0	4.45
1R Elec	1	5.1	Jul 2300	291	4.0	733.0	0.40
1R Elev Equip	1	0.8	Jul 2300	47	1.0	95.0	0.49
1R FAC	1	6.3	Jan 2300	360	0.0	300.0	1.20
1R Food Prep	1	12.5	Jan 2300	720	0.0	750.0	0.96
1R Huddle B1	1	1.9	Jan 2300	111	0.0	86.0	1.29
1R Huddle B2	1	1.9	Jan 2300	111	0.0	86.0	1.29
1R Huddle CTR A1	1	1.9	Jan 2300	111	0.0	86.0	1.29
1R Huddle CTR A2	1	1.9	Jan 2300	111	0.0	86.0	1.29
1R Huddle CTR A3	1	1.9	Jan 2300	111	0.0	86.0	1.29
1R Jan / FAC STOR	1	2.9	Jul 2300	169	3.2	337.0	0.50
1R LARGE TRAINING	1	28.5	Sep 1400	1637	9.2	1120.0	1.46
1R M Room	1	0.6	Jan 2300	37	0.0	90.0	0.41
1R Mail Equip	1	77.8	Jul 2300	4464	4.4	13333.0	0.33
1R Mail Work	1	8.9	Jul 1800	512	7.0	967.0	0.53

Zone Sizing Summary for Lower 1

Project Name: First Premier Bankcard Paper
Prepared by: Innovative Engineering Solutions

04/19/2008
07:20AM

Zone Name / Space Name	Mult.	Cooling Sensible (MBH)	Time of Load	Air Flow (CFM)	Heating Load (MBH)	Floor Area (ft²)	Space CFM/ft²
1R Mech	1	7.2	Jan 2300	414	0.0	1307.0	0.32
1R N Conf	1	5.7	Jan 2300	329	0.0	300.0	1.10
1R N Intv	1	4.2	Jul 1000	242	4.8	95.0	2.55
1R N Open Office Space	1	379.6	Jul 1500	21776	95.4	19095.0	1.14
1R NOC	1	11.1	Jan 2300	639	0.0	1966.0	0.33
1R North Vestibule	1	5.2	Jun 1800	298	10.1	152.0	1.96
1R Office 25	1	1.4	Jan 2300	78	0.0	140.0	0.56
1R Office 26	1	1.4	Jan 2300	78	0.0	140.0	0.56
1R Office A	1	1.4	Jan 2300	78	0.0	140.0	0.56
1R Office A (BY MW)	1	1.5	Jul 2300	86	1.0	140.0	0.61
1R Office A (BY REFRESH)	1	1.4	Jan 2300	78	0.0	140.0	0.56
1R Office A BY ELEV	1	1.3	Jan 2300	77	0.0	138.0	0.56
1R Office B (BY MW)	1	2.4	Jul 1800	138	3.0	140.0	0.99
1R Office B (BY REFRESH)	1	1.4	Jan 2300	78	0.0	140.0	0.56
1R Office B BY ELEV	1	1.4	Jan 2300	78	0.0	140.0	0.56
1R Office B1	1	1.4	Jan 2300	78	0.0	140.0	0.56
1R Office B2	1	1.4	Jan 2300	78	0.0	140.0	0.56

Air System Design Load Summary for Lower 1

Project Name: First Premier Bankcard Paper — 04/19/2008
Prepared by: Innovative Engineering Solutions — 07:20AM

	DESIGN COOLING			DESIGN HEATING		
	COOLING DATA AT Jul 1400 COOLING OA DB / WB 93.3 °F / 72.8 °F			HEATING DATA AT DES HTG HEATING OA DB / WB -16.0 °F / -16.7 °F		
ZONE LOADS	Details	Sensible (BTU/hr)	Latent (BTU/hr)	Details	Sensible (BTU/hr)	Latent (BTU/hr)
Window & Skylight Solar Loads	2403 ft²	61282	-	2403 ft²	-	-
Wall Transmission	10674 ft²	7885	-	10674 ft²	43576	-
Roof Transmission	0 ft²	0	-	0 ft²	0	-
Window Transmission	2403 ft²	20616	-	2403 ft²	123759	-
Skylight Transmission	0 ft²	0	-	0 ft²	0	-
Door Loads	120 ft²	4892	-	120 ft²	5504	-
Floor Transmission	40004 ft²	0	-	40004 ft²	31238	-
Partitions	0 ft²	0	-	0 ft²	0	-
Ceiling	0 ft²	0	-	0 ft²	0	-
Overhead Lighting	86242 W	294253	-	0	0	-
Task Lighting	0 W	0	-	0	0	-
Electric Equipment	46340 W	158111	-	0	0	-
People	791	197016	168092	0	0	0
Infiltration	-	0	0	-	0	0
Miscellaneous	-	0	0	-	0	0
Safety Factor	0% / 0%	0	0	0%	0	0
>> Total Zone Loads	-	744055	168092	-	204077	0
Zone Conditioning	-	748605	168092	-	216619	0
Plenum Wall Load	0%	0	-	0	0	-
Plenum Roof Load	0%	0	-	0	0	-
Plenum Lighting Load	0%	0	-	0	0	-
Return Fan Load	43555 CFM	0	-	43555 CFM	0	-
Ventilation Load	12876 CFM	212160	96828	12876 CFM	1132608	0
Supply Fan Load	43555 CFM	0	-	43555 CFM	0	-
Space Fan Coil Fans	-	0	-	-	0	-
Duct Heat Gain / Loss	0%	0	-	0%	0	-
>> Total System Loads	-	960765	264919	-	1349227	0
Central Cooling Coil	-	960765	264957	-	0	0
Central Heating Coil	-	0	-	-	1349227	-
>> Total Conditioning	-	960765	264957	-	1349227	0
Key:	Positive values are clg loads Negative values are htg loads			Positive values are htg loads Negative values are clg loads		

APPENDIX D. SAMPLE ENERGY REPORTS

This is the information calculated by the HAP program that reports the heating and cooling monthly loads, lighting and electrical energy consumed per month.

Monthly Simulation Results for Lower 1

Project Name: First Premier Bankcard Paper
Prepared by: Innovative Engineering Solutions

04/19/2008
07:24AM

Air System Simulation Results (Table 1) :

Month	Central Cooling Coil Load (kBTU)	Central Heating Coil Load (kBTU)	Supply Fan (kWh)	Lighting (kWh)	Electric Equipment (kWh)
January	0	96432	0	64164	34477
February	0	61912	0	57955	31140
March	0	22716	0	64164	34477
April	11663	45	0	62094	33365
May	143312	0	0	64164	34477
June	299691	0	0	62094	33365
July	546098	0	0	64164	34477
August	308720	0	0	64164	34477
September	113286	0	0	62094	33365
October	23902	0	0	64164	34477
November	0	11270	0	62094	33365
December	0	69011	0	64164	34477
Total	**1446671**	**261386**	**0**	**755482**	**405937**

APPENDIX E. SAMPLE WELLFIED SIZE AND DESIGN

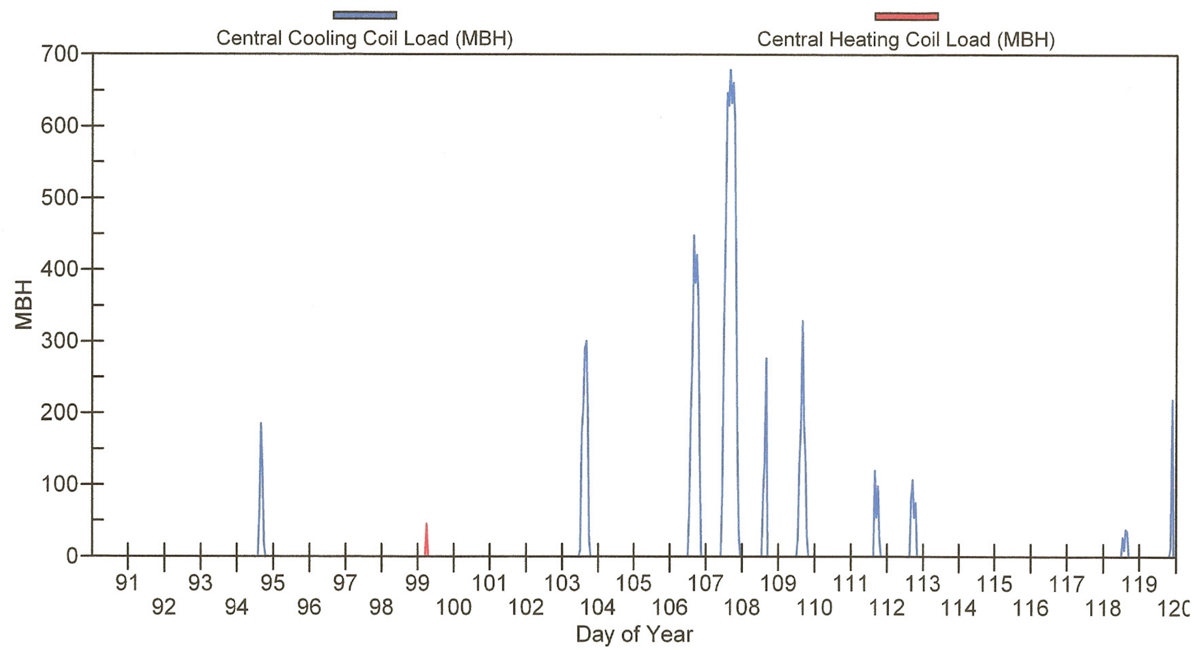
These are the reports provided by the HAP program that are hourly reports of peak heating and cooling requirements per month. This information is used to calculate the well field for a ground source heat pump system.

Hourly Simulation Results for Lower 1

Project Name: First Premier Bankcard Paper
Prepared by: Innovative Engineering Solutions

04/19/2008
07:25AM

Hourly Simulation Results for Tuesday, April 1 (day 91) thru Wednesday, April 30 (day 120)



APPENDIX F. ELECTRICAL / GAS RATE SHEETS

Energy rates for gas and electric provided by the US Government as well as XCEL Energy and MidAmerican Energy.

Energy-Controlled Service (Non-Demand Metered) Prices

This optional service is available to Xcel Energy customers with permanently connected, separately served, interruptible electric heating loads of 10 kilowatts (kW) to 50 kW that are under Xcel Energy's control. Loads served would include storage space heating, water heating systems and other loads subject to Xcel Energy approval which can be served by electricity and an alternate fuel. When Xcel Energy's system demand increases to near the level where we need to use less efficient power plants, or we set new peak demands, electric service is interrupted and the customer uses the alternate fuel to supply heating needs. If you select this service, you must remain on it for a minimum of one year. Your monthly bill will show:

- Basic Service Charge of $2.50.
- Energy Charge per kWh of $0.0353.
- Optional Energy Charge of $0.0353, October through May, and $0.0725, June through September, is available to customers with heat pump installations for non-interruptible service during June through September billing months.

The Fuel Clause Adjustment and other charges when applicable also appear on your monthly bill. See details later.

Limited Off Peak Service Prices

This optional service is available to Xcel Energy customers with permanently connected loads which the customer or Xcel Energy would control and energize only from 10 p.m. to 6:30 a.m. daily. The Energy Charge per kWh is $0.0270 for Secondary Voltage Service and $0.0264 for Primary Voltage Service. Additional customer and monthly minimum charges apply based on service voltage and phase.

Automatic Protective Lighting Service Prices

This optional service is available to customers desiring nighttime security lighting. For each lighting unit your monthly bill will show one of the following charges:

Area Units	
100 Watts (W) High Pressure Sodium (HPS)	$6.50
175 W Mercury*	$6.50
250 W HPS	$12.25
400 W Mercury*	$12.25
Directional Units	
250 W HPS	$13.70
400 W Mercury*	$13.70
400 W HPS	$18.00
1,000 W Mercury*	$31.50

* *Available to existing installations only.*

The Fuel Clause Adjustment and other charges when applicable also appear on your monthly bill. See details later.

Fuel Clause Adjustment

Xcel Energy's costs vary from month to month for fuel (coal, uranium and natural gas) and purchased power used to provide electricity. Your bill reflects these adjustment. When costs rise above the amount established in the kWh prices shown, we add the increase to your bill. When the cost decreases, we deduct the difference from your bill.

Minimum Charge

Your monthly minimum bill will always include the Basic Service Charge or any applicable Customer Charge even if energy use for the month is zero.

City Fees

Xcel Energy collects fees for the communities of Fedora and Forestburg from Small General Service customers by including a surcharge on customer bills in these communities to cover part of the cost of providing streetlighting.

Sales Tax

State sales tax applies to charges for utility service, Fuel Clause Adjustment, city fees and city sales taxes. The following cities charge a city sales tax: Alexandria, Baltic, Bridgewater, Canistota, Canova, Canton, Carthage, Centerville, Chancellor, Crooks, Dell Rapids, Emery, Garretson, Harrisburg, Lennox, Marion, Monroe, Ramona, Salem, Sioux Falls, Tea and Worthing.

Service Processing Charge

Xcel Energy will charge $12 connection charge the first time service is established or when it's reestablished.

Late Payment Charge

If you do not pay the amount due by the due date shown on the bill, Xcel Energy may add a late payment charge of 1 percent of the unpaid portion to the next month's bill.

Returned Check Charge

Xcel Energy charges $15 for any payment check or draft dishonored or returned by a financial institution.

Other Information

This folder does not include all prices, rules and regulations. Complete rate schedules and terms and conditions for these and other optional rate services are available by calling the Xcel Energy Business Solutions Center at 1-800-481-4700.

Xcel Energy
414 Nicollet Mall
Minneapolis, MN 55401
1-800-481-4700
www.xcelenergy.com

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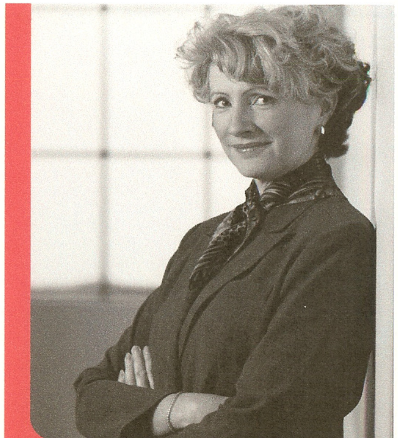
Northern States Power Company d/b/a Xcel Energy



XCEL ENERGY SOUTH DAKOTA COMMERCIAL AND INDUSTRIAL ELECTRIC PRICES

(EFFECTIVE MAY 1, 1993)

Xcel Energy

MidAmerican ENERGY

MIDAMERICAN ENERGY COMPANY
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FILED with the SOUTH DAKOTA P.U.C.

Section No. 3
Original Sheet No. D-11
Canceling IPS Section No. IV 10 Fifth Rev. Sheet No. 14,
#10 Third Rev. Sheet No. 15 and
10W and 10H Original Issue Sheet Nos. 16 & 16A

Class of Service General Service, Base - Energy Only Metering - Price Schedule GBD

Available In the Company's South Dakota electric service area.

Applicable The general service electric base energy only metering service is:

- Applicable to all electric service required on premises.
- Not applicable to customers with demands greater than 200 kW.
- Subject to applicable terms and conditions of the Company's Rules and Regulations and Electric Rate Applications.
- Not applicable to standby or supplementary service, except where the customer is operating an alternate energy production facility or a qualifying cogeneration or small power production facility.

Price The monthly price schedule for base energy only metering is:

GBD Price Schedule	Summer per kWh	Winter per kWh
Service Charge	$10.00	$10.00
First 4,000 kWh @	$0.0885	$0.0842
Additional kWh @	$0.0630	$0.0554

Seasonal Provision Summer and winter periods are defined as:

- Summer - June through September Billing Periods
- Winter - October through May Billing Periods

Price Adjustment The prices charged through the energy cost adjustment are calculated as shown on Sheet No. C-1. The purpose is to track energy (including fuel and purchased interchange energy) costs.

Tax Adjustment Service provided according to this price schedule is subject to state and local taxes as well as any franchise fee calculations applicable to any city in which the premise is located. See Sheet No. C-2.

Payment Terms Service bills are due and payable within 20 days from the date the bill is rendered to the customer. When not paid in full by this date, a late payment charge of 1.5 percent of the unpaid balance is added to the next bill.

Issued: November 8, 1995
Issued by: Brent E. Gale
Vice President-Law and Regulatory Affairs

Effective with billings on and after
December 1, 1995

Natural Gas Prices

(Dollars per Thousand Cubic Feet)

Data Series: Wellhead Price **Period:** Annual

Show Data By: Data Series / Area	2001	2002	2003	2004	2005	2006	View History
U.S.	4	2.95	4.88	5.46	7.33	6.42	1922-2006
Alabama	4.23	3.48	5.93	6.66	9.28		1967-2005
Alaska	1.99	2.13	2.41	3.42	4.75		1967-2005
Arizona	4.12	2.60	4.33	5.12	6.86		1967-2005
Arkansas	4.99	4.43	5.17	5.68	7.26		1967-2005
California	6.93	2.92	5.04	5.65	7.45		1967-2005
Colorado	3.84	2.41	4.54	5.21	7.43		1967-2005
Florida							1967-1995
Illinois							1967-1994
Indiana	3.28	3.11	5.41	6.30	9.11		1967-2005
Kansas	3.66	2.61	4.33	4.94	6.51		1967-2005
Kentucky	4.78	3.01	4.54	5.26	6.84		1967-2005
Louisiana	3.99	3.20	5.64	5.96	8.72		1967-2005
Maryland	4.15	5.98	4.50	6.25	7.43		1967-2005
Michigan	3.47	2.16	4.01	3.85	5.30		1967-2005
Mississippi	3.93	3.06	5.13	5.83	8.25		1967-2005
Missouri							1967-1997
Montana	3.12	2.39	3.73	4.51	6.57		1967-2005
Nebraska	2.16	1.52	3.17	3.22	4.29		1967-2005
New Mexico	3.89	2.68	4.56	4.97	6.91		1967-2005
New York	5.00	3.03	5.78	6.98	7.78		1967-2005
North Dakota	3.53	2.73	3.53	5.73	8.40		1967-2005
Ohio	4.54	4.52	5.90	6.65	8.72		1967-2005
Oklahoma	4.03	2.94	4.97	5.52	7.21		1967-2005
Oregon	3.66	3.97	4.48	3.89	4.25		1979-2005
Pennsylvania				NA	NA		1967-2005
South Dakota	3.42	2.95	4.98	5.49	7.44		1979-2005
Tennessee	3.60	3.41	5.22	6.90	9.55		1967-2005
Texas	4.12	3.16	5.18	5.83	7.55		1967-2005
Utah	3.52	1.99	4.11	5.24	7.16		1967-2005
Virginia							1967-1995
West Virginia				NA	--		1967-2005
Wyoming	3.49	2.70	4.13	4.96	6.86		1967-2005

Last Updated 10/31/2007
- = No Data Reported; **NA** = Not Available; **W** = Withheld to avoid disclosure of individual company data.

Notes: Gas volumes delivered for use as vehicle fuel are included in the State annual totals through 2005 but not in the State monthly components. Through 2001, electric power price data are for regulated electric utilities only; beginning in 2002, data also include nonregulated members of the electric power sector. See Definitions, Sources, and Notes link above for more information on this table.

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