Implementation of Sustainable HVAC Systems in Commercial Structures

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***Abstract*- In recent years, policy makers and environmentalists have brought energy efficiency, sustainability and renewable resources to the forefront of the construction industry. While most agree that sustainable methods of construction and renovation deserve attention, consensus often dissolves around the costs of capital and installation associated with these unconventional technologies. This research focuses upon the commercial application of sustainable building concepts within the field of heating, ventilating and air conditioning (HVAC). The paper points out the fiscal and logistical elements that need to be considered on a case-by-case basis among builders, architects, engineers and owners before deciding whether or not these sustainable methods of heating and cooling are feasible for their individual projects. Fiscal elements include: operating and maintenance costs, retrofitting existing equipment, longevity of the mechanical equipment, energy savings and incentives. Logistical elements include: subsurface conditions, regional climate, access to the site and mechanical equipment, retrofitting existing equipment, insulating factors of the structure, building codes, energy and environmental design criteria, and design principles incorporated into the layout of each facility. The culmination of this data will be presented in a matrix, which will allow these individuals to confidently pursue sustainable HVAC systems.**

Index Terms – Efficiency, Fiscal, Logistical, HVAC, sustainable.

DISTINGUISHING SUSTAINABLE HVAC SYSTEMS

Sustainable HVAC systems are designed to consume fewer natural resources than traditional systems from the date of initial assembly to demolition of the structure in which they are emplaced. During this lifespan, expectations of performance include longevity, reduced maintenance, higher efficiency, and better indoor air quality for heating, cooling and ventilating a structure. This combination of expectations leads to better building efficiency, comfort, and productivity for stakeholders.

There are two basic tiers for acquiring sustainable HVAC practices. The first is level is Leadership in Energy and Environmental Design, LEED, and the second is Environmental Management Program, EMP. The "Green" concepts of design presented by LEED are where the construction industry is currently directed for sustainable building design beyond traditional methods and building codes, but the EMPs are the next phase in ensuring the highest level of indoor and environmental sustainability.

Reference [1] states, "LEED is an internationally recognized green building certification system, providing third-party verification that a building or community was designed and built using strategies aimed at improving performance across all the metrics that matter most: energy savings, water efficiency, CO2 emissions reduction, improved indoor environmental quality, and stewardship of resources and sensitivity to their impacts."

An EMP is a long-term, all-encompassing set of goals and directives based upon the ideals of the U.S. Environmental Protection Agency, EPA, and LEED is considered a subdivision of EMP (albeit an independent third-party). LEED strives to certify a particular project as "Green" in comparison to currently accepted building practices, whereas EMP is aimed at zero net energy use, and optimization of all other elements, which include occupancy comfort, productivity, longevity, and countermeasure for preserving the Earth's decreasing resources despite society's increasing demands. Reference [2] states, "rule-of-thumb "Green Guidelines" and "Best Practices" are insufficient for EMPs because they may lead to incorrect HVAC system and equipment selection and sizing [because] EMPs require careful planning, application of sound engineering principles, and life-cycle maintenance considerations." That is, LEED can be considered the first step towards EMP, but the goals and objectives are different. This paper will consider both EMP and LEED certified HVAC units sustainable, but it is important to note that both types are not equally sustainable.

Conventional Equipment

Conventional HVAC equipment can be considered all means associated with direct consumption of fossil fuels or less efficient use of electricity. These units include:

- Forced air furnaces
- Gas-fueled boilers
- Wood-fueled boilers
- Oil burners
- Wood burners
- Air cooled condensers
- Wood furnaces

- Air-source heat pumps (in comparison to geothermal)
- Un-insulated sheet metal plenums

Operation of Conventional Equipment

Forced air furnaces consume nonrenewable sources of fuel or large amounts of electricity to heat air and then distribute/force it throughout a structure with a fan and ductwork.

Gas-fueled boilers burn natural gas or propane, which are both nonrenewable resources that subject the consumer to volatile pricing in the marketplace. The heat produced is used to heat water and distribute this gain through radiant units or circulating air within a plenum.

Wood-fueled boilers burn organic cellulose material, which is a slowly renewable resource that emits large amounts of carbon and particulates into the atmosphere. The heat produced is used to heat water and distribute this gain through radiant units or circulating air within a plenum.

Oil burners burn petroleum, which is a nonrenewable resources that subjects the consumer to volatile pricing in the marketplace. The heat produced is used to directly heat a space by radiation or circulating air with a fan.

Wood burners burn organic cellulose material, which is a slowly renewable resource that emits large amounts of carbon and particulates into the atmosphere. The heat produced is used to directly heat a space by radiation or circulating air with a fan.

Air cooled condensers use refrigerant to exchange heat content between indoor air and outdoor air. The conditioned air is then circulated through the structure by blowing air over the coils of the condenser with a fan and through a plenum.

Wood furnaces burn organic cellulose material, which is a slowly renewable resource that emits large amounts of carbon and particulates into the atmosphere. The heat produced is directly distributed throughout the structure by circulating the heat with a fan through a plenum.

Air-source heat pumps are capable of removing heat from air in order to supply cooling, as well as reversing the cycle to add heated air to a structure. The units are powered by electricity and utilize the outdoor air as a heat source or sink. Efficiency is limited by the fluctuation of environmental conditions. Extreme humidity levels and temperature drastically reduce the performance and efficiency of such heat pump units.

Un-insulated sheet metal plenums are rectangular or circular in shape. The circular plenums are the preferred design due to aesthetics when exposed, improved cleanliness from limiting the flat surface area for collecting dust, and the optimization of air flow. A circular duct does not create areas of dead air space because the interior surface is continuous, rather than rectangular with ninety degree corners. Both designs however, are not considered to maximize efficiency unless insulated to minimize heat transfer.

Sustainable Equipment

The sustainable units do not utilize fossil fuels and minimize the use of electricity through high efficiency. These units include:

- Biomass-fueled boilers
- Off-peak thermal energy storage, or thermal energy storage (TES)
- Air-to-air energy recovery equipment, or Heat-Recovery Ventilators (HRV's) and Energy-Recovery Ventilators (ERV's)
- Geothermal heat pumps
- Radiant heat
- Solar Flat-plate collectors
- Solar concentrating collectors
- Solar vacuum-tube collectors
- Solar packaged (plug-and-play) units
- Textile-based plenums
- Piped, sealed, and insulated plenums

Operation of Sustainable Equipment

Biomass-fueled boilers burn organic pellets, which are an easily renewable resource. The heat produced is used to heat water and distribute this gain through radiant units or circulating air with a fan through a plenum. Reference [3] states, "[w]ell-designed biomass-fueled boilers have very high burning efficiencies which reduce particulate emissions to less than half of the levels of the best wood stoves." Higher efficiency assists in cost savings, as well as reducing environmental pollution.

Off-peak thermal energy storage units utilize thermal-storage materials to conduct heating and cooling operations during off-peak hours of energy consumption in preparation for the following peak hours of consumption. This is beneficial because it assists utility companies in the avoidance of black-outs or power shortages. The use of such equipment is rewarded by utility companies awarding the owner with a reduced rate for power during these off-peak hours.

Air-to-air energy recovery equipment is capable of capturing up to 90% of the heat from indoor air before it is exchanged for fresh make-up from outside a structure during heating and vice versa for discharging heat prior to cooling. Reference [3] states, "ERV's also provide humidity conditioning using a desiccant wheel or plates made of a permeable material; these help retain indoor moisture during the heating season and exclude it during the cooling season." This capability is paramount when factoring dry-bulb temperature, relative humidity (RH) and average wet-bulb temperature (Mean Coincident Wet Bulb, MCWB) differences between the desired indoor air and outdoor air.

Geothermal heat pumps are capable of removing heat from air in order to supply cooling, as well as reversing the cycle to add heated air to a structure. The units are powered by electricity and can be ground-source or water-source. The ground-source units use the earth's stable temperature below grade as a heat source and outlet (sink). Water-source units utilize similar stability properties below the surface of water near the bottom of a pond. Fluid is conditioned within lines under the water or ground and exchanged with air moving into, or out of a structure. The heat content is exchanged within the sink and the conditioned fluid then distributes this gain or loss by circulating air over the coils with a fan and into a plenum.

Radiant heat utilizes the natural tendency of warm air to rise through the air column within a space, rather than using additional energy to disperse heat throughout a plenum. Sources of the heat supplied can be geothermal, solar, boiler, electric, or steam. For maximum sustainability, geothermal and solar sources are preferred.

Solar Flat-plate collectors use reflectors to concentrate solar thermal energy upon heat collection fluids. These fluids are formulated to optimize the collection of heat at high temperatures. The fluid is then directed into a distribution system in order to directly supply radiant heat within a structure or plenum.

Solar vacuum-tube collectors create a one-way heat collection system. Solar radiation is allowed to naturally hit the tubing and it is captured within the vacuum. The flow of heat then terminates at a collection point where it is transferred to water and pumped into radiant units within a structure or plenum.

Solar packaged (plug-and-play) units may be designed for various applications, which include: space heating, water heating, power generation and wastewater treatment.

Textile-based plenums are made of cotton, polyester or fiberglass, and are zippered to allow for easy connection of multiple sections. The use of these materials reduces the consumption of nonrenewable resources that are used to fabricate sheet metal plenums. Application is limited to spaces where the noise generated from the initial expansion is not considered polluting. Once inflated, the fabric does not allow sound to transfer as would a metal plenum made of solid material.

Piped, sealed and insulated plenums are valued for minimization of heat transfer, leaks, and noise. Piped plenums are either imbedded in concrete floor slabs or lie below grade of the slab. Sealed plenums are coated with a compound that ensures an air-tight enclosure at all seems. Insulated plenums are sheet metal with internal or external insulation.

Logistical Parameters

The design and implementation of a sustainable HVAC system will take extensive coordination and time commitment by all parties in order to achieve a sustainable environment. This is another factor of reluctance for many looking into the application of such technology because the process is often seen as a short-term slow down or increase in risk, rather than a long-term sustainable investment. Special considerations must be made in the design of the building in regards to subsurface conditions, regional climate, and ensuring that the system's longevity will be supported well into the future by making equipment easily accessible for maintenance, as well as the ability to add capacity for expansion to the facility. These factors must all be addressed before the HVAC contractor can begin to design a sustainable system.

Calculating Size of HVAC Units

To make a rough calculation for sizing an existing unit or budgeting during the planning phase of construction there are formulas available which allow the consumer to get an approximation of the size of heating and cooling units needed to properly regulate the indoor air of a structure. Depending upon what region of the country a structure is built and the degree to which the envelope is insulated will dictate the variables. However, if the goal is to create an accurate design, a Residential Load Calculation must be done with computer software because an undersized unit will remain in one continuous cycle and an oversized unit will short cycle repeatedly. Both scenarios will lead to inefficiency, higher energy costs and premature failure of the equipment.

Reference [4] provides a map of the United States, which is divided into five separate heating and cooling regions. For example, the size of an air conditioning unit for a 3,000 square foot structure in northern Ohio would be 5 tons, or 60,000 Btu's because each ton of capacity is equal to 12,000 Btu's. To determine the size of the heating unit, the zone indicates 45-50 Btu's per square foot. These values indicate the poorly insulated variable and the well-insulated variable respectively, to be used in the following calculation:

$$\text{Size} = \frac{(\text{square footage})\left(\text{Btu's per square foot}\right)(\text{inefficiency})}{12{,}000 \text{ Btu per ton}}$$

Therefore, the 3000 square foot structure would require a 15 ton unit if it was poorly insulated (50 Btu per square foot) and using an 80% efficient heating system; 13.5 ton if well insulated (45 Btu per square foot) with 80% efficient unit; 13.5 ton if poorly insulated (50 Btu per square foot) with 93% efficient unit; and 12.5 ton if well insulated (45 Btu per square foot) with 93% efficient unit.

The use of such a formula is an approximation, but it portrays the significant difference in achieving the proper design. The 12.5 ton unit would under-perform in the structure that required a 15 ton unit and the latter would short-cycle if placed in the structure that required a 12.5 ton unit.

References and Guidance

To aid in early design or answer the questions of potential project owners, the author of this paper recommends utilizing the free software package available online through MIT, *The MIT Design Advisor* or Environmental Building News' *GreenSpec Directory*. Reference [5] states, "The MIT Design Advisor is a tool which allows you to describe and simulate a building in less than five minutes. No technical experience or training is needed. An annual energy simulation can be run in less than a minute."

Subsurface Conditions

Subsurface conditions are primarily a concern with geothermal heat pumps due to the depth needed to maximize the efficiency of the ground loop. In most regions the optimum depth of the ground loop is 60 feet. For this reason, a geotechnical report is paramount in determining the depth of bedrock and the water table, which can negatively impact the cost of installation, as well as the environment.

Access to the Site and Mechanical Equipment

Site conditions refer to all obstacles that may interfere with the installation of a sustainable system, whether it is for new construction, retrofitting or maintenance. Obstacles may include overhead power lines, shallow bedrock, large trees, parking lots and garages, narrow alleys, crowded streets, hillside terrain or underground utilities. Drilling rigs used to install geothermal wells are most susceptible to unfavorable site conditions due the size and nature of the equipment. Solar installation can also be difficult in urban settings due to shade from surrounding buildings.

Mechanical equipment access refers to the degree of ease for maintenance personnel to service or add-on to existing systems. Due to the very design elements that make geothermal and radiant systems so efficient, the two are difficult to service or use in remodeling applications. While the actual mechanical equipment of these systems is made easily accessible, the piping is below ground or contained within concrete, which is why it is paramount for these applications to be far more sustainable and durable than traditional HVAC equipment.

Regional Climate

Regional climate analysis goes beyond the seasonal temperature averages. The elements to be analyzed include the latitude and elevation of the site, and comparing the desired indoor air conditions to those of the air outside of the building.

For heating, the data primarily focuses upon the dry-bulb temperature difference in °F between the indoor and outdoor air.

Cooling on the other hand, involves a wide variety of air conditions. Factors taken into consideration are dry-bulb temperature, relative humidity (RH) and average wet-bulb temperature (Mean Coincident Wet Bulb, MCWB) differences between the desired indoor air and outdoor air.

Building Design

Herein lays the largest and most critical element that can be controlled by man to improve the overall efficiency of the system and reduce capacity. Whereas designers, contractors and owners have no control over regional climate and subsurface conditions, they do have the ability to limit the capacity of HVAC equipment by utilizing responsible construction techniques. The building envelope and the materials incorporated into it have the potential of increasing the overall sustainability of the project.

Building design features can be adapted to aid in sustainability by minimizing the affects of heat transfer between outdoor and indoor air, as well as radiant light and heat from the sun. Infiltration (heating and cooling loss) can greatly be reduced by designing isolated control zones in entryways. These create a small zone with an exterior access door and an interior access door, which helps to prevent loss due to pressure differences, outdoor winds and radiant heat from the sun. Optimizing the efficiency of all openings (windows, doors and skylights) is beneficial whether they allow for infiltration or not. With hermetically sealed, gas insulated glass panels, sun screens, properly sized overhangs and low-e glass much of the negative effect of heat transfer and radiance can be minimized. Maximizing r-values in above-grade and below-grade walls and roofs, and creating dead air cavities between the building envelope (walls, roof and floors) and occupied spaces can also help to reduce heat transfer. Although, the surface area of HVAC supply lines running through these unconditioned dead air cavities must be kept to a minimum or extensively insulated to avoid heat transfer, which increases the load placed upon HVAC units, thereby decreasing efficiency. The efficiency of office equipment and lighting must also be maximized in order to minimize internal loads. It is important to consult the interior decorating as well because plants can emit 10-30 Btuh of latent heat and increase humidity in the space through transpiration.

Fiscal Parameters

Due to the complexity of HVAC equipment, the fiscal element of designing any system can be overwhelming for all parties involved. The owner of a project must rely upon the expertise of the general contractor, as well as the HVAC contractor. Many poorly designed systems are the result of contractors improperly sizing a unit by square footage or a human error made on such manual forms as the $N5_{AE}$ load calculation form (published by Air Conditioning Contractors of America, ACCA). In order to omit these errors, it is recommended that the general contractor or HVAC contractor utilize software design packages, but these packages present another fiscal burden because the HVAC contractor must offset the costs of the software package, as well as the estimators and engineers whom operate it.

In using sustainable systems, the high costs of design and equipment can be recovered through increased efficiency, eliminating unnecessary capacity, reduction of O&M, government provisions, longevity and increased productivity of occupants.

The increased productivity of occupants should be the main focus for justifying funds spent during construction because this coupled with the efficiency of a sustainable unit is what drives profit. Reference [2] shows the "[t]ypical 30 year building costs: 92% occupancy, 2% initial construction, and 6% operating costs." If the productivity of occupants can be increased, the profit margin will assist in offsetting the burden of wages and the sustainability of the HVAC equipment will aid in offsetting the increased initial cost of construction by drastically reducing operating costs.

Incentives

The Heating Seasonal Performance Factor (HSPF), Seasonal Energy Efficiency Rating (SEER or EER), and Coefficient of Performance (COP) are the equipment efficiencies that this paper will focus upon for comparison. HSPF is the ratio of thermal energy output (in Btu) to electrical energy input (in watt-hours) over a heating season. Similarly, SEER (also referred to as EER) is the ratio of cooling performance. COP is the ratio of energy input (in Btu) to energy output (in Btu).

On top of choosing equipment that rate high in these efficiencies, there may be local and state government tax provisions available in different regions, this paper will address those available in all regions at the federal level and the Solar Renewable Energy Credits (SREC) which half of the states have enacted.

The Emergency Economic Stabilization Act (EESA) provides a 15 year accelerated depreciation rate for commercial HVAC equipment that would normally be calculated over a 39 year period. The current deadline for eligibility ends in 2013. Each claim must be prepared by an engineer in accordance with standards set by the U.S. Department of Energy. Up to $0.60 per square foot may be awarded in three different categories, which include interior lighting, HVAC systems, and the building envelope. Total savings could be as high as $1.80 per square foot. For contractors, it is important to note that the person responsible for designing a government-owned building or project may be able to receive the claim.

The SREC credits are complex in nature because up to four separate parties can be involved with the transaction. The states which have adopted the use of this credit program are attempting to encourage the development of alternative energy. Each SREC is equivalent to 1,000 kWh of solar generated electricity and each individual state sets an annual quota for the utility companies supplying their power. The quota gets larger year after year, but the value of each SREC actually reduces in value; encouraging swift development in the beginning years when credits are worth the most amount of money. The utility companies must meet their annual quota or face being charged with an alternative compliance credit (ACP).

In order to avoid the ACP, the utility companies are permitted to purchase SREC rights to private solar panel projects. The owners of these private projects get to maintain ownership of their photovoltaic cells and the solar energy which they produce. What they are selling, is an intangible green credit to the power company or any trader that is willing to purchase the SREC. To summarize, the government sets the mandate, the utility company must follow or be penalized, the utility company attempts to buy private project SREC's to avoid penalty, but traders are competing with the utility companies to buy private SREC's in order to force a shortage on the market and make the utility companies buy from them at an inflated price.

Capital & Installation Cost

Direct capital costs are calculated into the overall cost of installation within the matrix and not all fields are populated due to lack of pricing disclosure from the industry source and irrelevance to commercial applications.

Oil-fueled boilers and burners, as well as wood-fueled boilers, furnaces and burners were eliminated from this study due to the negative impact such units have upon the environment. The EPA is currently assessing the particulate discharge of these fuel sources to determine the necessity of placing restrictions on use in certain regions. Of particular interest, are the outdoor wood furnaces and boiler systems which allow individuals to burner combustibles that would normally be poisonous to burn within a structure. These combustibles include painted and treated lumber, and railroad ties.

Operation and Maintenance (O&M)

Operational costs are highly dependent upon energy costs, which indicate the need for higher efficiency and sustainability. The consumer is no longer able to ignore the high costs associated with the consumption of nonrenewable resources in conventional HVAC units because government regulation and incentives are geared towards increased sustainability. In addition, as utility companies are pushing towards deregulation it becomes paramount. The threat of deregulating electricity prices, coupled with the increasing cost of fossil fuels has the potential to drastically close the gap between the rate of return on an investment (ROI) in sustainable HVAC systems to the annual cost of operating a conventional system.

Maintenance costs are independent of energy costs, but are dependent upon longevity, equipment usage, accessibility and the cost of nonrenewable resources used in repairs. Equipment usage will not vary between conventional applications and sustainable applications because neither have any control on weather conditions. However, the cost of maintenance will be significantly greater for conventional HVAC units because the design parameters do not include longevity, accessibility and resource minimization. LEED and EMP programs ensure that these design parameters are met by sustainable units in an attempt to reduce damage to the environment, as well as save the consumer money and expedite ROI.

MATRIX

DECISION MATRIX FOR HVAC SYSTEMS IN NORTHERN OHIO COMMERCIAL STRUCTURES

Equipment	Capital & Installation Cost (per square foot)
Traditional	
80% Efficient Forced Air Furnace and AC in a Poorly Insulated Structure	$14.58
80% Efficient Forced Air Furnace and AC in a Well Insulated Structure	$13.13
93% Efficient Forced Air Furnace and AC in a Poorly Insulated Structure	$12.54
93% Efficient Forced Air Furnace and AC in a Well Insulated Structure	$11.29
Air-source Heat Pump	Cost is equivalent to Forced Air Furnaces
Gas-fueled Boiler	$3.50-$4.00
Wood-fueled and Oil-fueled systems were excluded due to environmental costs	-
Sustainable	
Biomass-fueled Boiler for 10,000 SF Structure	$22.97
Biomass-fueled Boiler for 50,000 SF Structure	$5.52
Biomass-fueled Boiler for 100,000 SF Structure	$4.50
Commercial Photovoltaic (PV) Power System 12,078 kWh per year	$3,329 (unit cost after incentives)
Commercial Photovoltaic (PV) Power System 56,364 kWh per year	$0, $6740 profit (unit cost after incentives)
Commercial Photovoltaic (PV) Power System 112,728 kWh per year	$131,595 (unit cost after incentives)
Off-peak Thermal Energy Storage Cooling	-
Air-to-air Energy Recovery Equipment (ERV), Light Commercial 5 Ton Unit	$2.78
Air-to-air Energy Recovery Equipment (ERV), Medium Commercial 10 Ton Unit	$1.69
Air-to-air Energy Recovery Equipment (ERV), Heavy Commercial 20 Ton Unit	$1.31
Geothermal Heat Pumps	-
Radiant Heat	-

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REFERENCES

U.S. Green Building Council, "What LEED Is", *www.usgbc.org*, 2010, LEED tab: Intro.

Grahame, M., E., Milestone, B., Milestone, P., E. "Energy Master Planning for HVAC Systems in New and Existing Buildings", *National Institute of Building Sciences: WBDG: Whole Building Design Guide*, 03-14-2007, 9.

Atlee, J., Malin, N., Piepkorn, M., Wilson, A. "Mechanical Systems/HVAC", *GreenSpec Directory 7th Edition*, 242-243.

AC Direct, Inc., "System Sizing Help", *http://www.acdirect.com/systemsize.php*, 1999-2008.

Ali, Z., Glickman, L., Gouldstone, J., Lehar, M., Ray, S., et al., "The MIT Design Advisor", *http://designadvisor.mit.edu/design/*, 2000-2009.