ENERGY MASTER PLANS for SUSTAINABLE, HIGH PERFORMANCE HVAC & ASSOCIATED SYSTEMS for HOT AND HUMID CLIMATES

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INTRODUCTION

An energy master develops long term facility plans to move a facility toward net zero energy, high performance productivity and long-life systems for minimal material use. This is achieved by a number of small, easy steps and at a rate and schedule determined by the owner. Projects will eventually reduce HVAC and associated systems energy, maintenance and remodeling life cycle costs by 75% while at the same time dramatically improving comfort and productivity. The savings come from using proven planning, design and construction methods and equipment.

"Current HVAC systems cost more to install, use more energy, require more maintenance and produce poorer indoor air quality than they used to." Amory Lovins, et al, on offices throughout the USA circa 1990.
This statement is still true today.

Energy Master Plans (EMPs) examine the pieces of true sustainable design and then assemble the pieces into whole sustainable, high performance HVAC systems. These are presented to the owner as the target to reach. A detailed, in depth energy master plan is the ideal way to achieve these goals, moving from the current HVAC systems to better and better systems until truly sustainable, high performance systems are in place. The number of steps and the pace of the program is determined by the owner.

We will move directly to sustainable, high performance systems as the intermediate steps are totally arbitrary and dependent on theowner, the facilities and systems currently in place. There are many engineering and physical aspects that would take books to cover in detail, but the essential goals, objectives and winning strategies can be covered briefly to allow for a general understanding of the fundamentals of true sustainability and high performance in HVAC and associated systems.

The USGBC, through LEED™ guidelines, is taking the first small steps toward better design, construction and operation of buildings. However, like other professional organizations, the guides originate from committee decisions that may not provide the best solutions.

The other main obstacle to sustainable, high performance is the engineers and architects fees which remain fixed to the gross construction cost with none or even adverse incentives to reduce long-term energy and maintenance or improve comfort and productivity.

Table 1. A Typical New 100,000^{2}ft Office Block

	STANDARD HVAC SYSTEM	CURRENT"GREEN " HVAC SYSTEM	SUSTAINABLE, HIGH PERF. HVAC SYSTEM
Installation Cost	$2.3M	$2.3M	$3.2M
50 Year Energy Costs	$13M	$10M	$2M
50 Year Operation and Maintenance Costs	$9M	$8M	$3M
50 Year Installation and Modification Costs	$17M	$15M	$8M
50 Year Total Costs	**$39M**	**$33M**	**$13M**

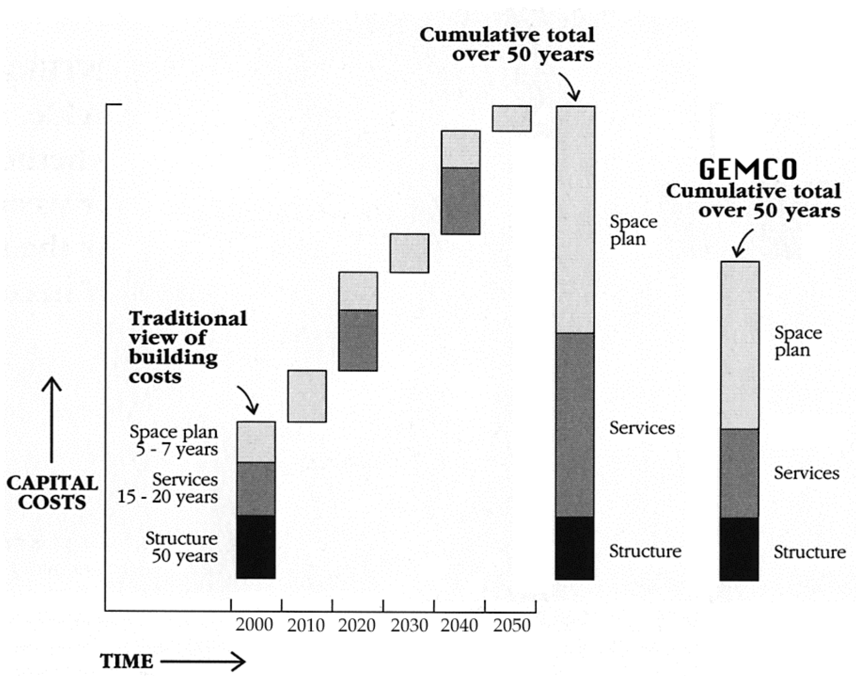
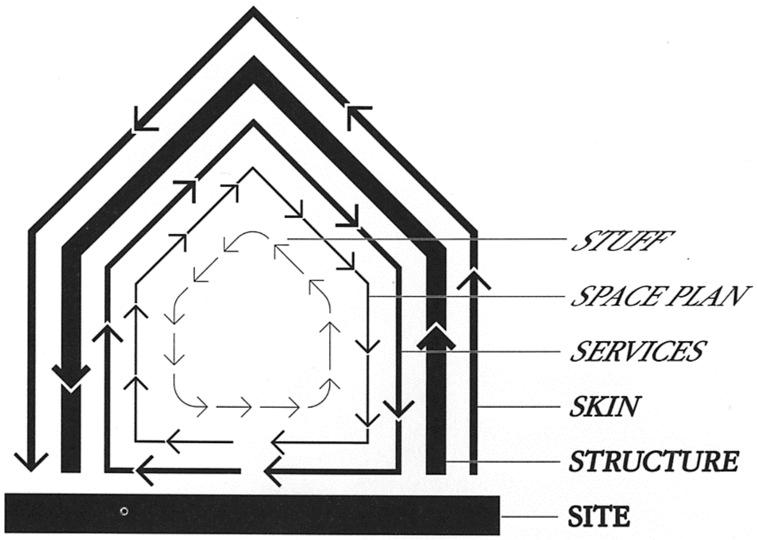


Figure 1. REDUCING THE 50 YEAR HVAC OPERATING & ENERGY COSTS BY 75%.
From How Buildings Learn by Stuart Brand



SHEARING LAYERS OF CHANGE. Because of the different rates of change of its components, a building is always tearing itself apart.

Figure 2. EMP'S WILL DOUBLE THE SERVICES LIFE CYCLE.
From How Buildings Learn by Stuart Brand

Energy Master Plans initially focus on four essential design initiatives to create sustainable, high performance HVAC systems:

1. Design for sustainable maintenance:
   - All moving parts in plantrooms;
   - All equipment easy to maintain;
   - Reduce maintenance burden over time.
2. Optimize comfort and productivity by separately controlling temperature, humidity and ventilation control:
   - Radiant temperature control;
   - Desiccant humidity control;
   - Effective 100% ventilation air control.
3. FLAME[3]:
   Flexible, Long-life, Adaptable, Maintainable, Expandable, Efficient and Effective.
   - Equal pressure piping systems;
   - Equal pressure ducting systems;
   - Modular heating and cooling generation, small zone control.

4.Complexity:
   If you cannot understand the system without explanation, it is too complex.
   If you need to read a sequence of operation more than once, it is too complicated.

DEFINING AN ENERGY MASTER PLAN

An energy master plan is a long-term plan, 20 to 100 years, for a facility's energy systems. Using whole building design, it will take a facility's energy systems and move them to net zero energy use over the long-term. An EMP will also optimize comfort and productivity to maximize income for the facility. The EMP will also maximize systems life cycle and minimize remodeling and additions costs. The program will progress at a rate depending on the building owners plan and the economic feasibility of renewable energy sources.

The main weapon in an EMP is the improvement of the building envelope. Optimizing the envelope is essential to allowing the HVAC system to become sustainable. Daylighting, ventilation, thermal and moisture control must all be optimized.

An energy master plan assesses foreseeable changes to a building's usage. It plans for modifications and alterations, expansions and rehabs and plans for the energy systems to adapt to these changes in the most economically feasible manner.

DEFINING A HOT AND HUMID CLIMATE

Most areas in the South East USA and through Texas have what is considered a hot and humid climate. However, comparing the Summer design temperatures and humidity, it is as hot and humid in the Mid Atlantic as in the South East. A temperature of 100^0F with high humidity occurs in both areas. The difference is the high humidity and temperature occurs for a longer period annually, causing a higher average temperature, which will require a different strategy for the HVAC system energy sources. The stress on the HVAC system and building is the same due to the same design conditions so a similar size and type of HVAC system and the building fabric. The average annual temperature in the Mid Atlantic may be 55^0F and the average annual temperature in the South East 65^0F. It is this 10^0F or 15^0F higher average temperature and prolonged periods of high humidity that demands different sustainable answers to HVAC design.

DEFINING SUSTAINABLE, HIGH PERFORMANCE HVAC AND ASSOCIATED SYSTEMS

Defining the terms Sustainable and High Performance is essential to set out Goals and Objectives for the systems.

According to the dictionary, the definition of sustainability is:

1. Able to be maintained. Sustainable design should focus on the maintainability and the operability of the energy systems over the life cycle of the facility, and focus on greatly extending the life cycle of the energy systems by working the components at their best operating condition.
2. Exploiting natural resources without destroying the ecological balance of a particular area. While it is not essential for a project to be net zero energy immediately, it must be planned and designed so that it can be converted with the minimum of effort to a zero energy facility when the renewable sources become economically viable.

The definition of a high performance system is:

1. A system that has the ability to provide superior functions and/or operations. High performance comfort and productivity is the focus here. Providing optimum comfort and productivity actually produces more monetary rewards than all other monetary returns combined.

These definitions and monetary rewards would logically bring optimum comfort and the maintainability of a facility to the very forefront of any sustainable design. Even on sustainable and green designs, most HVAC systems and their associated energy systems offer only average comfort conditions and are less maintainable than they ever were.

PREPARATION AND PLANNING

A Short History of HVAC System Design and the Needed improvements

Willis Carrier is recognized as the father of air conditioning. He started commercial building HVAC systems a hundred years ago.

Current design methods and equipment sizing and selection are much the same as they were one hundred years ago, designs use a 75^0F temperature as the design criteria and calculate system and plant sizes in a very similar manner as Willis Carrier did. There have been little advances in equipment, only electronic sensors and computer controls are significantly different, otherwise someone coming from a hundred years ago would recognize current HVAC systems.

For HVAC systems to become sustainable in energy, long-lived and produce optimum conditions for comfort and productivity, there must be a drastic improvement in the systems and equipment and an equally drastic improvement in the design methods. Carbon emmissions (fuel and electricity use) must be reduced by 75%, the equipment must last two or three times longer, and the comfort conditions require an huge improvement, 5% to 10%.

The fundamental shift required in HVAC system selection is to move from an air system that is used to control temperature, humidity and ventilation all together to a system that separates temperature, humidity and ventilation control. Distribution systems require a paradigm shift to flexible, long-lived, adaptable, maintainable and expandable systems. The systems must be designed to last and be maintainable efficiently for over sixty years. These three changes open wide the door to the long-term efficiency and effectiveness increases that we need to develop truly sustainable, high performance systems.

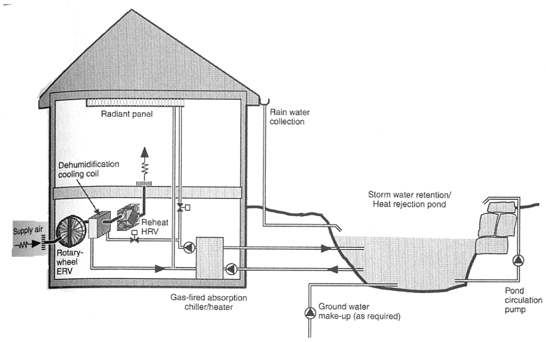


Figure 3. A System with Some Sustainable, High, Performance Features

__Performance Assessment and Analysis of Existing HVAC Systems__

We have examined and tested over 1,000 buildings from new to over 100 years old. The efficiency and effectiveness of thousands of HVAC systems has been examined and evaluated over 40 years. A critical assessment of the comfort and productivity that the HVAC systems provide long-term under actual working conditions reveals poor results. A critical assessment of the maintainability and the operational effectiveness reveals very poor results. Assessing the flexibility, adaptability and expandability of the systems to changes that invariably happen to all facilities over time also reveals very poor results. Overall, there are extensive improvements required for HVAC systems planning and design for new and existing facilities.

This experience of analyzing over 2,000 existing working HVAC systems is the basis for proposing a paradigm shift in HVAC systems selection for long-term maintainability. Systems with many of the features proposed are already in operation throughout Europe and are gaining a foothold in North America, mostly on the West Coast. Applying these systems to hot and humid climates will simply require a better performing envelope and a better humidity control system. The proposed system will also perform for better for longer, being more flexible, adaptable, maintainable and expandable.

There are issues that have govern the long-term design, construction and operation of facilities:

1. The facility effectiveness and efficiency is the direct result of the upper management objectives and strategies. If upper management considers comfort and productivity an issue, then it will be improved. If upper management considers energy efficiency and overall maintenance effectiveness an issue, it will improve. The opposite is also true, in other words, it all comes from the top!
2. Maintenance personnel are particularly vulnerable as a target for cost cutting, even when the maintenance department is well run. It actually costs money to downsize an efficient maintenance department, because for every cent spent on an effective maintenance program, 3 cents are saved.
3. Manufacturers have exerted a disproportionate amount of influence on the design process, due to the lack of expertise shown by the HVAC designers.

Currently, there is little connection and exchange of information between designers, contractors and facility operators. The only common member is the equipment manufacturer, who is currently in an influential position in the construction industry. The building industry is separated into design, construction and operation segments. Some of the best trained HVAC engineers in Europe came from contractors that designed, built and maintained a facility. The best of the engineers were the commissioning team. The commissioning team checked the design for long-term efficiency and workability and then followed construction and start-up, and often re-commissioned the facility every three to five years before the maintenance contract was renewed.

__Comfort and Productivity__

HVAC systems are installed in buildings for one overriding purpose, to increase the comfort and productivity of the occupants.
HVAC systems have moved backward over the last forty years, creating sick building syndrome and fungal growth, and less comfortable conditions than ever before.

Considering the billions of dollars spent annually on office, hospital and factory workers wages and the billions of dollars spent on schools and Universities, there has been relatively little research over the last 100 years into the detailed effects of HVAC systems on productivity. Although the conditions required for comfort by humans vary considerably, there are fundamental requirements and guidelines for various criteria that can be controlled and so a comfort level that increases productivity can be attained.

One glaring hole in the thermal comfort assessment of most current HVAC systems is the lack of radiant control. A human being is twice as sensitive to radiant temperature than to air temperature, yet air temperature is almost exclusively the medium that is controlled and often cited as the thermal comfort predictor. We need to control the radiant temperature more than the ambient temperature for thermal comfort. A radiant temperature system using water in pipes, serpentined in the ceiling and floor, walls, etc., not only will provide better comfort, but it can move energy around ten times more efficiently than a fan moves air and also use lower temperature differences for heating and cooling, making it more efficient to generate heating and cooling energy and easier to move to renewable energy sources.

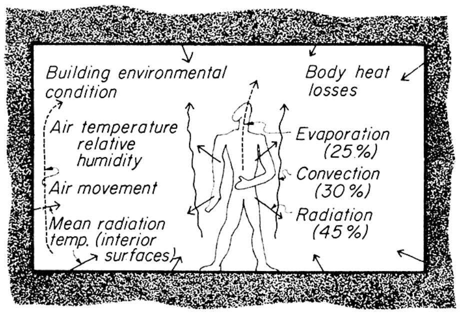


Figure 4. The Body has the three forms of heat. Radiation rate is over 50% more than the Convection Rate. Evaporation Rate is almost equal to the Convection Rate.

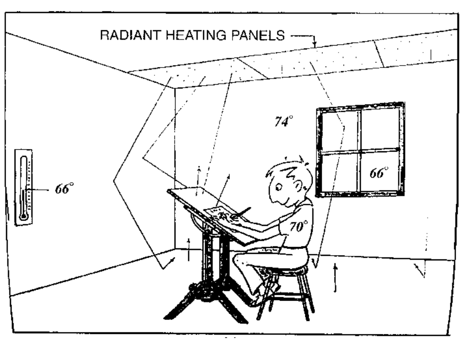


Figure 5. Radiant Heating

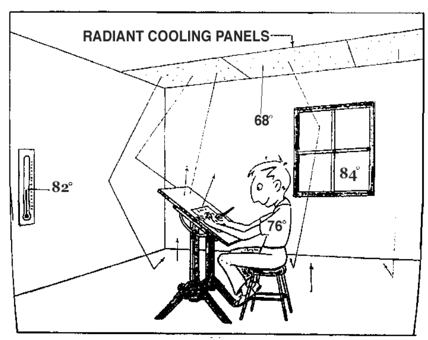


Figure 6. Radiant Cooling

Humidity control is another aspect of comfort grossly underestimated. Humidity affects more than comfort, it directly effects the health through other biological aspects of humans, the sinuses, eye dryness, skin dryness, breathing, and indirectly through electrical static charges, etc. A liquid desiccant type humidity system can be three times more effective than a cooling coil type system, particularly as it can also provide effective humidification as well.

Recommended ventilation rates range historically from 50cfm per person to 5cfm per person for the same activity. Ventilation effectiveness of a HVAC system is a relatively new ingredient in the ventilation equation. Providing an adequate supply of ventilation air that is free from contaminants should be the goal of the ventilation system. A displacement ventilation system is three times more effective than an overhead diffuser type system.

HVAC Energy Use, Analysis and Reduction Targets

Electrical energy is a high intensity energy that most often generated from carbon emissions.

Electricity is the primary target to minimize. Fans and pumps use about 50% of the HVAC electricity. Variable speed drives are supposed to reduce this by 30% to 70% but usually reduce it by 30% at most, and do not reduce the maximum demand and in some cases increase the maximum demand, and with substantial extra costs in maintenance. We need to reduce the fan and pump energy by at least 80% annually, and reduce the maximum demand by over 75%. It is the HVAC system selection and in particular the distribution systems that require to be carefully selected and designed to achieve long-term minimum electrical use.

Electrical refrigeration uses only 25% of the electricity but causes the electrical demand to rise considerably. We need to eliminate refrigeration or minimize at the very least.

An increase of 2% per year in energy use due to deteriorating efficiency is not unusual, particularly if the systems are not maintenance friendly. An increase of 5% to 10% in energy use after a HVAC system has been modified half way through its 40 year life is also the norm. These increases add up to a considerable increase over time, perhaps up to 25% to 40% increases.

WINNING STRATEGIES

Failing to plan is planning to fail! The initial step for any design should be an energy master plan. An energy master plan is ideally dovetailed with a facility master plan, focusing on the energy systems. An energy master plan looks at the long term goals and objectives for the building or facility's energy systems. It takes into account modifications and rehabs as well as changes in whole building or part building usage. It looks at long term goals and strategies for the building/facility including occupant requirements and productivity, IEQ, energy usage and energy and maintenance costs. The energy master plan should be used as a systematic method for producing sustainable, high performance buildings with a long term goal of net zero energy, optimum productivity and minimum operating and remodelling costs.

Energy Master Planning

Once an energy master plan has been developed, other winning strategies are more effective because the long term goals have been defined.

Integrated Design

The AIA energy guide stresses "The greatest opportunities for saving costs over the life of a building occur at the beginning of the design process". A holistic design process integrates each system design with the whole building design and the whole building design with each system. The design process is itirative and must be scrupulously documented in detail from day one. There are computer programs that perform good, integrated energy analysis for small and large buildings, Energy 10 and Energy Plus. These programs should be used for building orientation, fabric assessment and window and daylighting assessment, as well as used for HVAC system sizing and plant sizing. Energy Plus can be used to predict comfort but great care must be taken. HVAC system selection and sizing remains a problem for all computer programs to simulate so great care and caution is needed with the application and unfortunately there is so far no substitute for expert detailed HVAC system knowledge.

Decision criteria for air-conditioning systems (e.g. VAV, FCU) vs natural ventilation systems				
Design criteria	Variable air volume	Fan-coil units	Displacement ventilation	Natural ventilation
Ease of installation	1	3	5	5
Commissioning requirements	3	3	5	5
Floor-to-floor height	2	3	3	2
Temperature control	4	5	2	1
Humidity control	2	3	4	1
Multi-zone control	5	5	5	1
Air movement	4	3	4	2
Air cleanliness	4	3	4	2
Odour control	1	2	4	2
Noise control	2	3	4	1
Flexibility	1	2	3	3
Capital cost of plant	3	2	4	5
Maintenance costs	3	2	4	5
Running costs	3	4	5	5
Total	37	43	56	41
A score between 1 and 5 is given with 5 representing a positive feature.				

Figure 7. A Tabular Comparison of HVAC Systems by Ken Yeang. The assessment is typical, not accurate for long-term or any actual installation. Every building and situation requires its own individual assessment.

Maintenance Design

Sustainable maintenance is essential for every successful project. Check every detail for ease of maintainability. The three rules of sustainable maintenance must be accounted for with every decision.

The three laws of sustainable maintenance are:
1. All moving parts must be in plantrooms.
2. If it's not easy to maintain; it won't be maintained.
3. Maintenance time and effort will be reduced over time.

A HVAC system that will work efficiently and effectively for 40 to 60 years demands certain characteristics - FLAME3: Flexibility, Longevity, Adaptability, Maintainability, Expandability, Efficiency and Effectiveness. ASHRAE lists the average life expectancy and efficiency of equipment and components, but they can be doubled or halved by better or poorer design and construction.

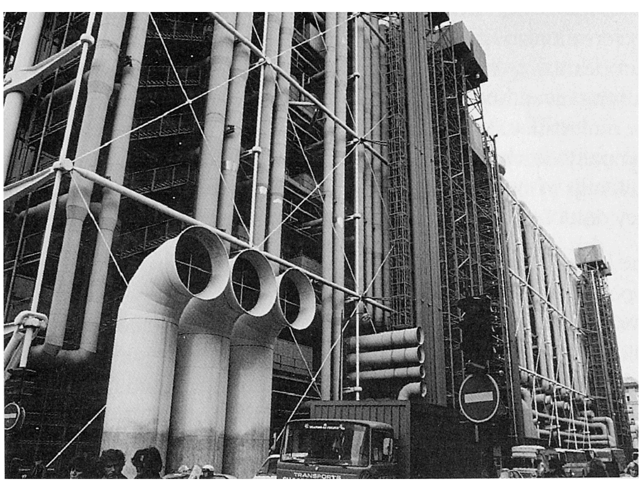


Figure 8. The Pompidou Center –
A Maintenance Nightmare

FLAME^3 Design

The first question the architect and engineer should ask the client about the HVAC systems are: How long do you want the HVAC systems to work for, and at what level of efficiency and effectiveness? Nearly every client would answer the same - at least 30 to 40 years, and very efficient and effective, with minimum initial cost. Although the initial construction cost can be up to 30% more than a current system, a simple payback of less than 4 years and the minimum life cycle costs will prove that a sustainable, high performance design is the most economical solution.

As an example: rooftop air handling units are the current design norm, even clusters of them on roofs. They cost 30% more than standard units, cost 20% more to maintain and last about half the life of a unit placed in a plantroom. The cost of a plantroom can often be offset by the savings in HVAC equipment cost alone, but the savings in operation, maintenance and replacement costs add to the burden of poor initial decisions. Further, the air units are responsible for 2/3 of the total pressure loss in the system, so increasing the AHU size to optimize flow through the unit has a payback less than 3 years if it is inside a plant room.

Every building goes through modifications and alterations during a forty year span, sometimes slight and sometimes quite significant changes. Most clients can hazard a guess at likely alterations and modification scenarios over a forty year period. Flexibility, Adaptability, Maintainability and Expandability of the distribution and generating systems are therefore essential design elements for any long-term success in a project.

As an example: a school can grow in population by 25% over forty years, and the internal room layout would prefer to be altered to take advantage of the latest teaching requirements about every 15 years. The systems need to be able to handle these different scenarios with the minimum of effort. This would help avoid the ubiquitous trailers that infest most school systems by allowing additions to be added as and when necessary and also allow the rooms to be flexible and adaptable to different uses. The distribution systems must be able to take a 25% increase in load without a problem and the zoning should be modular so that room layouts can be changed around without a problem.

An example of current design norm is to place variable frequency drives on every pump motor over 10hp, even the USGBC with LEED is recommending this poor practice. The analysis is that the variable drive will save money, an incorrect assumption. A variable speed drive is the mark of a poor design and one that will not only use more energy than it should but also be expensive to install and very expensive to maintain. Most central chilled water pumping systems will have a variable speed drive pump, and a variable speed drive standby, double the poor design! The piping system will be a standard flow and return system. The pump will use about 50% of the energy a non-variable speed pump uses over the year. The system is inflexible, unadaptable, expensive to maintain and non-expandable. If we install a reverse return piping system, optimized and over-sized by 25%, with a run pump that will pump 40% of the design flow and a high load pump that will pump 60% of the design flow, the cost will be marginally greater than the flow and return system with VFD's, but the energy use will be less than 10% of a standard system and the system will be flexible, adaptable, maintainable and expandable.

A current design solution to most problems is to add a control system or new piece of equipment, an example is the variable speed pump, adding an expensive addition to a poorly selected system. For every additional control actuator and piece of equipment comes an installation, operation and maintenance expense.

Radiant Temperature Control

Willis Carrier is called the father of air conditioning. Unfortunately, most people, including engineers and architects, believe this implies conditioning air to supply to a space or alternatively conditioning the air in the space by using air.

Radiant temperature control through the use of water circulated through pipes in the ceiling, floor, walls and even radiators and convectors, offers a very different concept in human comfort control and opens the door wide to drastic improvements in comfort control and minimizing energy use at the same time.

Using large areas of radiant cooling allows the temperature of the fluid to rise, away from the dewpoint temperature in the space. The higher temperature also allows more efficient cooling generation. Even single effect absorption refrigeration machines become quite efficient when generating 620F water. Heat form 2000F water for operating an absorption machine is readily available from solar collectors. If ground coupling or ground water is available near 620F, then the systems become even nearer to sustainable now.

Desiccant Humidity Control

Again, the Carrier mentality dictates that cooling coils remove moisture from the air, which means a refrigerant or cooling medium of around 45^0F, or lower, is required. If we move to desiccant humidity control we can make use heat to remove the humidity, often available when humidity is present, and then we only need a 62^0F medium for cooling. Moving from a 45^0F to 62^0F cooling medium can mean the difference between a sustainable and a non-sustainable strategy. Absorption machines can make 62^0F cooling water very efficiently using solar heat. A ground source of 65^0F is often available, or at least a 70^0F source. Liquid desiccant systems have been around since the early 1900's. There are liquid desiccant systems available that when designed properly and maintained reasonably, will last for 60 years, working efficiently and effectively. The initial cost is high and the payback may be over 3 years, but the long-term payback is big, really big.

Ground Source Heating/Cooling

Most areas in the USA North of a line between San Francisco and Richmond, VA have average temperatures and ground source energy that will enable most HVAC systems to totally eliminate refrigeration requirements. Areas South of the line can minimize refrigeration and non-renewable energy use by using ground source energy as a heating and cooling source. A water temperature of 62^0F will enable the complete elimination of refrigeration in most buildings and any temperature below 75^0F will be able to minimize the refrigeration load.

A balance of heat extracted to heat added should be designed into the systems where there is a heat balance requirement for continued use. in some cases this will mean employing tactics such as snow melting or similar tactics where it would normally be considered wasteful.

INTEGRATING ZERO ENERGY OPTIONS

Natural Ventilation

Natural ventilation is gaining popularity with many architects and engineers. There are several good concepts and several problems with natural ventilation systems. First the good: a well designed natural ventilation system provides contact with the outside and energy free ventilation, combined with cooling during temperate conditions. The main problem with current designs is that the building layout and designs tend to be inflexible and poorly adaptable so that the system falls into disuse quite soon. Allergies of the occupants can be a negative aspect of unfiltered outside air. Also, there is poor central or zone control with natural ventilation.

Perhaps the benefits of contact with the outdoors and individual control can be achieved by a sound system and individual radiant temperature control rather than opening windows.

A low energy option is mechanical extract that causes ventilation through the facility, a similar concept to a whole house fan used in residences.

Solar Thermal

Solar thermal is an excellent way to minimize the cooling loads, using desiccant dehumidification and absorption refrigeration. Most summer days that are the warmest can generate sufficient heat for conditioning a building.

Solar PhotoVoltaics

This will become more economically feasible as the price of gas rises and the cost of PV decreases.

Natural Lighting/Daylighting

Natural daylighting is the best way to optimize productivity of the occupants. Schools with the best daylighting have experienced up to a 20% plus increase in test scores, so optimizing daylight would seem a no-brainer. Careful design to avoid glare and direct sun is required. There are excellent computer programs that allow quick assessment of daylighting that also assess the thermal consequences of windows, etc. (for example: Energy 10, Square 1 and Energy Plus) . Optimizing the selection of the glazing type for light penetration and thermal insulation will provide the best of both worlds. One word on office blocks with full height glazing: the consequence of a full height window is that a radiant floor is required (together with a radiant ceiling) to remove the solar heat as it starts to warm the floor and help keep the internal conditions comfortable.

Integrating natural lighting/daylighting with the artificial lighting and then integrating both with the building thermal design can be readily assessed by the computer programs. Again, HVAC simulation requires expertise that the programs do not offer accurately.

BUILDING TYPES AND SUSTAINABLE, HIGH PERFORMANCE DESIGNS

The climate assumed for these buildings is a Philadelphia climate. This climate has both a cold and dry winter for a challenging heating system, and a hot and humid summer for a challenging cooling system. Similar climates are found for half the USA and other hot and humid areas do not have the heating challenges. Other, less challenging climates need less stringent building envelope systems and HVAC systems to achieve similar results.

Utilizing the winning strategies as described in this article, we can now look forward to the following results. In all cases, an energy master plan has been put into use and long-term goals for the buildings will be incorporated into each design. Changes and modifications in building and building usage have also been delineated in the energy master plan that allows for $FLAME^3$ designs to be incorporated.
Table 2.

Primary School

The first experience for children other than their home is the primary school. Making this experience a delight will start the learning process away from home on a positive footing. The particular challenge of a primary school is that children tend to stay in the same room for most of the day. For this reason it is essential to have the optimum natural daylighting available. This feature gives sufficient sensory variance and mood stimulation to retain more interest in the environment and assist learning up to a 25% improvement. Building modifications and extensions ideally take place every seven to ten years, and our system allows this with minimum costs and effort.

The HVAC system can be simple systems with small zones. A larger classroom may have more than one zone to assist in rezoning when the building is modified. The piping distribution system need only be split into two or three zones to cover the small footprint and uses of the school. The air systems can cover multiple sections or areas but care must to be taken to consider future modifications and the effect on the air systems. $FLAME^3$ is the watchword in design. The maintenance requirements call for two plantrooms at most to minimize maintenance.

NUMBERED SYSTEMS ARE ON THE ELEMENTARY SCHOOL	1. STANDARD ELEMENTRY SCHOOL	2. OPTIMIZED STANDARD	INDIVIDUAL ROOM HEAT PUMPS	OPTIMIZED CENTRAL HEAT	OPTIMIZED HT. PUMPS W/GROUN	3. SUSTAIN., HIGH PERF.
TEST	**0%**	**2%**	**0%**	**2%**	**2%**	**6%**
INSTALLATION -	$0.5M	$0.45M	$0.4M	$0.4M	$0.4M	$0.4M
INSTALL PIPEWORK	$0.1M	$0.3M	$0.2M	$0.25M	$0.25M	$0.5M
CHILLER/BOILER	$0.3M	$0.2M	$0.4M	$0.35M	$0.2M	$0.05M
CONTROLS	$0.1M	$0.1M	$0.1M	$0.1M	$0.1M	$0.1M
GROUND LOOPS	$0.0M	$0.0M	$0.0M	$0.0M	$0.4M	$0.55M
INSTALLATION	**$1M**	**$1M**	**$1.1M**	**$1.1M**	**$1.35M**	**$1.6M**
ANNUAL MORTGAGE	$100K	$100K	$110K	$110K	$135K	$160K
ENERGY	$140K	$110K	$130K	$105K	$65K	$25K
MAINTENANCE	$95K	$65K	$95K	$65K	$65K	$30K
1st YR TOTAL	**$335K**	**$275K**	**$335K**	**$280K**	**$265K**	**$215K**
SIMPLE PAYBACK ENERGY & MAINT.	**BASE**	**0 YRS**	**10 YRS**	**1.5 YRS**	**3.3 YRS**	**3.3 YRS**
10 YR MORTGAGE	$1M	$1M	$1.1M	$1.1M	$1.35M	$1.6M
ENERGY	$1.9M	$1.5M	$1.7M	$1.3M	$0.8M	$0.3M
MAINTENANCE	$1.1M	$0.8M	$1.1M	$0.8M	$0.8M	$0.35M
MODS/REPAIRS	$0.4M	$0.2M	$0.4M	$0.2M	$0.2M	$0.05M
10 YR TOTAL	**$4.4M**	**$3.5M**	**$4.3M**	**$3.4M**	**$3.15M**	**$2.3M**
20 YR MORTGAGE	$2M	$2M	$2.2M	$2.2M	$2.7M	$3.2M
ENERGY	$4M	$3.2M	$3.6M	$2.9M	$1.9 M	$0.6M
MAINTENANCE	$2.6M	$1.9M	$2.6M	$1.9M	$1.9M	$0.7M
MODS/REPAIRS	$0.9M	$0.4M	$1.2M	$0.4M	$0.4M	$0.2M
20 YR TOTAL	**$9.5M**	**$7.5M**	**$9.6M**	**$7.4M**	**$6.9M**	**$4.7M**
30 YR MORTGAGE	$2M	$2M	$2.2M	$2.2M	$2.7M	$3.2M
ENERGY	$6.4M	$5M	$5.8M	$4.7M	$3M	$0.9M
MAINTENANCE	$4.3M	$3M	$4.3M	$3M	$3M	$1.1M
MODS/REPAIRS	$2.0M	$0.8M	$2.6M	$0.8M	$0.8M	$0.3M
30 YEAR INSTALLATION & OPERATING	**$14.7**	**$10.8**	**$14.9**	**$10.7**	**$9.5M**	**$5.5M**

Secondary School

After enjoying such a rich environment as the primary school, with natural daylighting being a primary feature, little difference is preferred with the secondary school, but the size and layout of the schools tend to reduce natural lighting availability. Although the schools tend to be much larger in size, the HVAC systems can be similar. Distribution system should be separated into more zones, possibly using about 30,000ft^2 to 60,000ft^2 as a zone. The maintenance requirements call for two or three plantrooms at most to minimize maintenance, or about one plantroom per every 50,000ft^2 to 100,000ft^2.

Table 3.

NUMBERED SYSTEMS ARE ON THE "OFFICES" SCHEMATIC DIAGRAMS	1. STANDARD SECONDARY SCHOOL	OPTIMIZED CONSTANT VOLUME SYSTEM	INDIVIDUAL ROOM HEAT PUMPS	OPTIMIZED CENTRAL HEAT PUMPS	OPTIMIZED HT. PUMPS W/GROUND SOURCE	2. SUSTAIN., HIGH PERF. SYSTEM
TEST	**0%**	**2%**	**0%**	**2%**	**2%**	**6%**
INSTALLATION -	$0.45M	$0.4M	$0.4M	$0.4M	$0.4M	$0.4M
INSTALL PIPEWORK	$0.15M	$0.3M	$0.2M	$0.25M	$0.25M	$0.5M
CHILLER/BOILER	$0.3M	$0.2M	$0.4M	$0.35M	$0.2M	$0.05M
CONTROLS	$0.1M	$0.1M	$0.1M	$0.1M	$0.1M	$0.1M
GROUND LOOPS	$0.0M	$0.0M	$0.0M	$0.0M	$0.4M	$0.55M
INSTALLATION	**$1M**	**$1M**	**$1.1M**	**$1.1M**	**$1.35M**	**$1.6M**
ANNUAL MORTGAGE	$100K	$100K	$110K	$110K	$135K	$160K
ENERGY	$140K	$100K	$130K	$105K	$65K	$25K
MAINTENANCE	$95K	$65K	$95K	$65K	$65K	$30K
1st YR TOTAL	**$335K**	**$265K**	**$335K**	**$280K**	**$265K**	**$215K**
SIMPLE PAYBACK ENERGY & MAINT.	**BASE**	**0 YRS**	**10 YRS**	**1.5 YRS**	**3.3 YRS**	**3.3 YRS**
10 YR MORTGAGE	$1M	$1M	$1.1M	$1.1M	$1.35M	$1.6M
ENERGY	$1.9M	$1.2M	$1.7M	$1.3M	$0.8M	$0.3M
MAINTENANCE	$1.1M	$0.8M	$1.1M	$0.8M	$0.8M	$0.35M
MODS/REPAIRS	$0.4M	$0.2M	$0.4M	$0.2M	$0.2M	$0.05M
10 YR TOTAL	**$4.4M**	**$3.2M**	**$4.3M**	**$3.4M**	**$3.15M**	**$2.3M**
20 YR MORTGAGE	$2M	$2M	$2.2M	$2.2M	$2.7M	$3.2M
ENERGY	$4M	$2.7M	$3.6M	$2.9M	$1.9 M	$0.6M
MAINTENANCE	$2.6M	$1.9M	$2.6M	$1.9M	$1.9M	$0.7M
MODS/REPAIRS	$0.9M	$0.4M	$1.2M	$0.4M	$0.4M	$0.2M
20 YR TOTAL	**$9.2M**	**$7.2M**	**$9.6M**	**$7.4M**	**$6.9M**	**$4.7M**
30 YR MORTGAGE	$2M	$2M	$2.2M	$2.2M	$2.7M	$3.2M
ENERGY	$6.4M	$4.4M	$5.8M	$4.7M	$3M	$0.9M
MAINTENANCE	$4.3M	$3M	$4.3M	$3M	$3M	$1.1M
MODS/REPAIRS	$2M	$0.8M	$2.6M	$0.8M	$0.8M	$0.3M
30 YEAR INSTALLATION & OPERATING	**$14.7M**	**$10.2M**	**$14.9M**	**$10.7M**	**$9.5M**	**$5.5M**

Office Block

The cost of the wages for offices will pay for the building twice over in a year in some cases. Optimizing the performance of these workers should be the financial goal of every good company director.

The classic problem presented to HVAC designers in office blocks is full height glazing being demanded by the client. This must not stop the HVAC system providing comfort, such requirements should simply result in consequences from the HVAC system design, in this case it will require a floor radiant system as well as a ceiling radiant system to counteract the full height glazing selection. Although this is not on the sustainable agenda, everything else can be accomplished, minimum energy and maintenance with maximum comfort and flexibility.

Moving and/or adding conference rooms is another common challenge to the HVAC systems. In this case, the distribution systems using FAME[3] will handle the problem.

Table 4.

	STANDARD VAV SYSTEM	UNDER FLOOR AIR SYSTEM	INDIVIDUAL ROOM HEAT PUMPS	OPTIMIZED CENTRAL HEAT	OPTIMIZED AIR SYSTEM	SUSTAIN., HIGH PERF. SYSTEM
TEST	**0%**	**1%**	**0%**	**2%**	**2%**	**6%**
INSTALLATION -	$0.5M	$0.55M	$0.4M	$0.45M	$0.4M	$0.4M
INSTALL PIPEWORK	$0.1M	$0.25M	$0.15M	$0.25M	$0.25M	$0.5M
CHILLER/BOILER	$0.3M	$0.2M	$0.4M	$0.3M	$0.1M	$0.05M
CONTROLS	$0.1M	$0.1M	$0.1M	$0.1M	$0.1M	$0.1M
GROUND LOOPS	$0.0M	$0.0M	$0.0M	$0.0M	$0.45M	$0.55M
INSTALLATION	**$1M**	**$1.1M**	**$1.1M**	**$1.1M**	**$1.3M**	**$1.6M**
ANNUAL MORTGAGE	$100K	$110K	$110K	$110K	$130K	$150K
ENERGY	$140K	$110K	$130K	$105K	$75K	$25K
MAINTENANCE	$95K	$70K	$95K	$70K	$65K	$30K
1st YR TOTAL	**$335K**	**$285K**	**$335K**	**$285K**	**$275K**	**$205K**
SIMPLE PAYBACK ENERGY & MAINT.	**BASE**	**1.7 YRS**	**5 YRS**	**1.7 YRS**	**3.2 YRS**	**3.3 YRS**
10 YR MORTGAGE	$1M	$1.1M	$1.1M	$1.1M	$1.3M	$1.6M
ENERGY	$1.9M	$1.5M	$1.7M	$3.1M	$0.9M	$0.3M
MAINTENANCE	$1.1M	$0.85M	$1.1M	$0.85M	$0.8M	$0.35M
MODS/REPAIRS	$0.4M	$0.4M	$0.4M	$0.2M	$0.2M	$0.05M
10 YR TOTAL	**$4.3M**	**$3.4M**	**$4.3M**	**$3.4M**	**$3.3M**	**$2.25M**
20 YR MORTGAGE	$2M	$2.2M	$2.2M	$2.2M	$2.6M	$3.2M
ENERGY	$4.0M	$3.2M	$3.5M	$3.1M	$2.2 M	$0.6M
MAINTENANCE	$2.6M	$2.05M	$2.6M	$2.05M	$1.9M	$0.7M
MODS/REPAIRS	$0.9M	$0.4M	$0.9M	$0.5M	$0.4M	$0.2M
20 YR TOTAL	**$9.45M**	**$7.7M**	**$9.45M**	**$7.7M**	**$7.4M**	**$4.7M**
30 YR MORTGAGE	$2M	$2.2M	$2.2M	$2.2M	$2.6M	$3.2M
ENERGY	$6.4M	$5.0M	$6.0M	$4.8M	$3.4M	$0.9M
MAINTENANCE	$4.3M	$3.2M	$4.3M	$3.2M	$3.0M	$1.1M
MODS/REPAIRS	$2.0M	$0.8M	$2.0M	$1.0M	$0.8M	$0.3M
30 YR TOTAL COST	**$14.7M**	**$11.2M**	**$14.5M**	**$11.2M**	**$10.0M**	**$5.5M**

Laboratory

Laboratories that have an interstitial floor are better maintained and allow for an uninterrupted workforce when maintenance is required. The cost of not having an interstitial floor is not only more maintenance cost and energy costs, but the interruptions to a valuable workforce. These interruptions alone will pay for the floor if a full financial accounting is used.

Careful planning for the air system and ductwork system will create a totally different HVAC system, as shown in the diagram, that does not rely on constant maintenance and adjustment. Also, the energy costs for this system can be drastically reduced, as well as the life cycle doubled from the present expectancy. It is still a better total accounting decision to have an interstitial floor.

Table 5.

	STANDARD VAV SYSTEM	STANDARD VAV SYSTEM WITH INTERSTITIAL FLOOR	CONSTANT/TWO VOLUME SYST WITH INTERSTITIAL FLOOR AND GRND SOURCE	SUST. HIGH PERF SYSTEM WITH INTERSTITIAL FLOOR AND GRND SOURCE
PRODUCTIVITY INCREASE	0%	2%	3%	5%
PRODUCTION $/YR/$M				$200,000
PRODUCTION INCREASE $M OVER				**$7M**
INSTALL DUCTWORK &	$400,000			$600,000
PIPEWORK	$100,000			$200,000
CHILLER/BOILER	$300,000			$50,000
CONTROLS	$200,000			$75,000
GROUND SOURCE	$0		$500,000	$600,000
INTERSTITIAL FOOR	$0	$300,000	$300,000	$300,000
TOTAL	**$1M**			**$1.6M**
MORTGAGE $/YR	$100,000			$160,000
ENERGY $/YR	$85,000			$20,000
MAINTENANCE $/YR	$130,000			$50,000
ANNUAL TOTAL	**$315,000**			**$240,000**
SIMPLE PAYBACK				
10 YR MORTGAGE	$1,000,000			$1,600,000
ENERGY	$850,000			$200,000
MAINTENANCE	$1,300,000			$500,000
MODS/REPAIRS	$300,000			$100,000
10 YR COSTS TOTAL	**$3.2M**			**$2.4M**
20 YR MORTGAGE	$2,000,000			$3,200,000
ENERGY	$1,800,000			$400,000
MAINTENANCE	$2,700,000			$1,100,000
MODS/REPAIRS	$700,000			$200,000
20 YR COSTS TOTAL	**$6.5M**			**$4.9M**
30 YR MORTGAGE	$2,000,000			$2,600,000
ENERGY	$2,700,000			$600,000
MAINTENANCE	$4,500,000			$1,700,000
MODS/REPAIRS	$1,300,000			$400,000
30 YR COSTS TOTAL	**$10.5M**	**$9.5M**	**$9M**	**$7.5M**

CONCLUSIONS

Failing to plan is planning to fail.

In order for a building's HVAC and energy systems to function optimally over the course of the systems' long lifecycle, a long-term plan must be put in place.

An energy master plan develops a Facility's HVAC and Energy Systems towards Sustainable, High Performance Systems by either a series of steps, steadily improving the performance of the systems, or by jumping forward more quickly and adopting sustainable, high performance practices sooner. The pace for achieving these goals is determined by the building owner.

By allowing for foreseeable changes that a building will undergo over the life of the energy systems, an EMP takes into account the churn, modifications, rehabs, extensions and changing usage that are at the heart of huge costs to the building owner and is able to greatly reduce these costs. At the same time, it produces vastly improved IEQ.

An energy master plan encompasses the winning strategies to produce a sustainable, high performance system including integrated design, maintenance design and FLAME[3].

In order to be successful, an energy master plan requires the adoption of common sense applied to the long-term plans for the HVAC and energy systems. Expert knowledge and full integration of the HVAC systems must also be applied with equal effort.

An energy master plan provides the guidelines, details and steps to take to produce what everyone is talking about today:
Truly Sustainable, High Performance HVAC and Energy Systems.

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