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HVAC Design and Operation for Green Buildings

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ABSTRACT

This paper describes the basic concepts of green building and discusses the role of HVAC for ensuring high performance sustainable buildings in design and operation. The design strategies for effective and green HVAC systems are explained and the new emerging HVAC technologies for green buildings are described. It is hoped that HVAC designers and other building professionals could develop a better understanding of green buildings and apply effective strategies and techniques for meeting the goal.

KEYWORDS: Green building, HVAC, design and operation.

1. INTRODUCTION

As natural resources rapidly deplete around the world, the need for green or environmentally friendly building practices is becoming more and more apparent. So-called "green buildings" are constructed or renovated under sustainable development, a design process that reduces the harmful impact on natural resources and looks at the life-cycle costs of the facility [von Paumgartten, 2001]. The benefits of green buildings are not difficult to understand. By following green design practices, building owners and developers can do well financially by doing good environmentally and socially. First, highly energy-efficient green buildings have lower operating costs than conventionally designed buildings. Second, sustainable design helps minimise broad environmental impacts, such as water usage, ozone layer depletion and raw materials usage. Finally, workers in well-lighted, safe, comfortable environments are productive and happy, which is a key factor in the current tight labour market.

This paper describes the basic concepts of green building and discusses the role of heating, ventilating and air-conditioning (HVAC) for ensuring high performance green buildings in design and operation. The design strategies for effective and green HVAC systems are explained and the new emerging HVAC technologies for green buildings are described. It is hoped that HVAC designers and other building professionals could develop a better understanding of green buildings and apply effective strategies and techniques for meeting the goal. With an integrated and holistic approach to HVAC and building design, a sustainable built environment can be achieved and the environmental performance of buildings can be improved.

2. WHAT IS GREEN BUILDING?

Despite all the discussions and advances in the world, understanding exactly what constitutes a green building is still not that well understood – even among many professionals [Traugott, 1999]. In simple terms, green buildings are energy and resource efficient, non-wasteful and non-polluting, highly flexible and adaptable for long-term functionality; they are easy to operate and maintain, and are supportive of the productivity and well being of the occupants. The design of a green building utilizes a whole-building, lifecycle approach. It should be noted that a green building is a continually evolving concept, a goal. What makes any particular building "green" is a unique solution that responds to the specific functional requirements and the climatic conditions of the building's location. In other words, "green" is different for every building. And, not every building is completely green in every aspect of its design. The important thing is to keep moving towards the goal.

From the viewpoint of HVAC engineer, high-performance green design is a common sense approach to building design. Within its scope, a building is seen as a single system made up of interdependent architectural and engineering components. High-performance design also takes into account the energy and environmental performance of the building during its complete life cycle, including site selection, construction, operations and maintenance, renovations, demolition and replacement. Figure 1 shows the concept of building life cycle and the four major aspects of sustainable construction, i.e. energy, water, waste and materials.

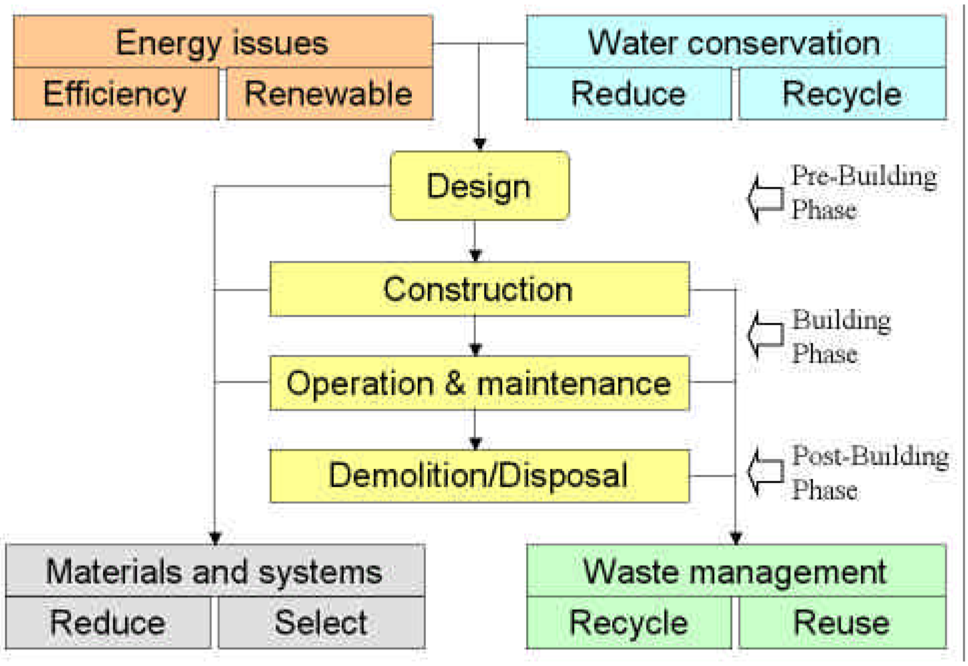

Figure 1 Building life cycle and sustainable construction

Green building emphasizes a "whole system" perspective and considers the construction process and first costs, toward the life of a building and the longer term interest of the owners and occupants. The high-performance, whole-building approach to design examines how a building interacts with its systems, activities and surrounding environment. As a significant portion of green building criteria are energy-performance related, the energy issues are usually a key factor in determining the environmental performance or responsiveness. Whole-building design methods that integrate passive solar, energy efficiency, and other renewable energy technologies are used to reduce building energy consumption. By optimising the building's standard components (site, windows, walls, floors, and HVAC systems) building owners can substantially reduce energy use without increasing construction costs. The most effective green design is a fully integrated design whereby architectural, HVAC and electrical systems all interact to minimize size, waste, energy use, and other negative impacts on the environment [Hartman, 2000].

3. THE ROLE OF HVAC

HVAC systems may damage the environment by unnecessary use of energy which results in depletion of non-renewable energy resources, principally fossil fuels, either by the generation of electricity or thermal energy, both of which contribute to environmental pollution [Centre for

Construction Ecology, 1998]. Environmental damage by HVAC systems may also be caused by appearance or noise, and by the discharge of contaminated water and air containing chemicals, lubricating oils, refrigerants, heat transfer fluids, particulate or gaseous matter, or microbiological organisms. In most situations, HVAC systems will significantly impact how "green" a building is. Therefore, the project team should not overlook the potential and influence when developing the design.

HVAC engineers can play a crucial role in environmental design by being the technical/analytical resource for the team, and by encouraging the development of more rigorous assessment tools that are appropriate, practical and friendly, and defensible. To make a difference for the green design goal, they should push architects to design better envelopes, encourage HVAC decisions be based on life-cycle costing, insert their influence earlier in the process and support the proper commissioning of buildings. They should also try to educate building owners or developers the value of a green/sustainable design so that the green process can be carried out successfully.

It is believed that the green design process requires a higher level of collaboration, interdependence and proactive effort among team members who are encouraged to cross traditional discipline boundaries with the shared mission to improve building performance. The architect or project manager is often responsible for creating and managing that process. The engineer should inform the process from a technical and scientific basis and to actively engage the other team members in the dialogue.

4. DESIGN STRATEGIES

Although HVAC systems offer many opportunities for recovery and re-use of thermal energy, the preferred solution is to use less energy in the first place. This is achievable by more energy efficient buildings, systems and equipment and through improved operating and maintenance procedures. More attention should be paid to the thermal characteristics of building and strategies for minimising internal loads, examining in detail the opportunities for natural ventilation and daylighting, and exploring ways to reduce the energy requirements of HVAC. For example, the use of high-performance glazing, insulation, and effective sun control can substantially reduce cooling and heating loads and the size of HVAC systems and components required to meet these loads. The ultimate objective is to minimise refrigeration requirements, or do away with refrigeration altogether, and to make use of renewable energy resources.

In order to design a better building, a green project team must rethink the design and construction process in terms of improving building performance. In addition to improving energy efficiency and environmentally sound operations, high performance sustainable design also seeks to provide an indoor environment that enhances the productivity of the occupants. Current research information suggests that good indoor environmental quality increases alertness and improves performance, while reducing illnesses and absenteeism. Sustainable design may thus provide significant life-cycle cost savings and productivity gains in addition to energy and resource savings.

It is essential for the design team to reexamine basic engineering principles in order to develop appropriate system design in support of a green building. Techniques such as natural ventilation, thermal-mass storage, radiant cooling and passive solar control are applications of basic thermodynamic principles. The designers must also help drive innovation and be an expert in understanding the technical characteristics and performance of architectural components, construction practices and maintenance/operational practices in terms of energy use, environmental impact and indoor air quality.

Computer-based energy analysis tools have become increasingly sophisticated and could enable the designer to evaluate the impact of the architectural configuration on energy performance and indoor air quality. Designers must become more sophisticated in their use of these tools, as well as financial analysis techniques, in order to determine the optimal configurations of architectural and engineering components, while meeting the typical budget, schedule and aesthetic requirements. For example, good indoor-air quality is achieved through a collaborative process between the architect and engineer. It begins with the effort to avoid potential sources of contaminants within the space. The engineer should assist the architect, the owner and the construction team in understanding the impact on indoor air quality of things like finish materials selections, contaminant-producing processes in the space (such as printing), HVAC system design and configuration, construction methods and operations and maintenance practices. The HVAC engineer must then design a system to achieve ventilation effectiveness for a given space layout. Computer tools, such as computational fluid dynamics, can assist the engineer in predicting the performance of the system.

While the engineer can become more aware and involved in these issues during the design process, it is also necessary to modify specifications accordingly. Strong specifications will be helpful in insuring that the space will be constructed in accordance with the high-performance design intent. It is incumbent on the design team to remain closely involved throughout the construction process or many of the benefits can be lost through inappropriate substitutions from contractors. The project will benefit from introducing the construction team to the "mission" of the building early on during the design process. They are then an invaluable ally in insuring the project constructibility and in maintaining the budget.

When a project is running late, the commissioning process is often rushed to achieve hand over, and the system is put into operation without ever having been properly regulated. This may be the principal cause of complaints for the whole of the life of the system. For a system to be successful, it must be designed to be commissionable, and the commissioning must be properly carried out [Stum, 2000]. A HVAC system must be operated as the designer intended or in a way to suit the client's new requirements in consultation with the designer. A proper regular system of monitoring, recording and maintenance must be in place.

The analysis of green building design can be time-consuming due to the many factors involved. A clear definition and holistic understanding of the design problem is important since the environmental equation is complex. For example, newly developed refrigerants, while more environmentally friendly, may be hazardous (e.g. flammable), be less energy efficient, require extensive re-engineering of existing systems or depend on the development of new refrigerating machines. When the energy requirements of new refrigerants are considered over the lifecycle of the equipment, the potential environmental damage resulting from the higher energy usage may outweigh that from possible leakage/disposal of the original refrigerant.

The design strategies for minimizing air pollution, wastewater and solid waste have been discussed by Sullivan (2001). It is believed that green building should use six distinct features to reduce consumption and pollution: resource-efficient building materials; designs that minimize materials and waste; contracts that assure waste-minimising job site management; and contracts that specify recyclable products, with recycled content.

5. NEW TECHNOLOGIES

Apart from the idea of sustainable, whole-building design as the "right thing to do", advances in technology are attracting the imaginations of building designers these days [Bobenhausen and Lahiri, 1999]. Underfloor air systems, radiant cooling and heating, building-integrated photovoltaics, fuel cells, sulfur and magnetic-induction-based lighting systems, high performance (low emissivity, spectrally selective) glazing, and increasingly sophisticated digital controls and sensors are being considered on many current projects. New systems and delivery methodologies are evolving and they may offer significant technical benefits to a project. A few important technologies that have the potential to improve the environmental performance of HVAC systems are described below.

(a) ***Underfloor air-supply systems***

This is a topic that has received a lot of coverage recently. Figure 2 shows a simple schematic of an underfloor air-supply system. Like most systems, there are both highly appropriate and less than ideal applications. Some pace-setting and sustainable designers find it interesting since all of the outside air is delivered to the building volume in close proximity to the occupants. Perhaps the most compelling applications are large, high spaces like convention centers and airport terminals, where potentially drafty air flows will be of minor concern to what is a continually transient occupancy. This concept of delivering cooling and ventilation air down low is becoming known as displacement ventilation.

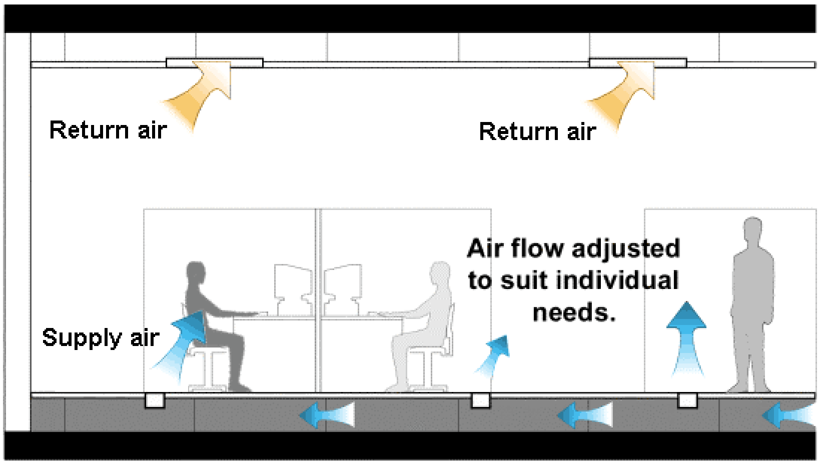

Figure 2 Underfloor air supply system
(Credit: Center for the Built Environment, University of California, Berkeley)

Another underfloor air-supply approach makes use of a plenum space that accommodates cabling systems for delivering conditioned air and avoids the need for air ducting. It is highly flexible and has the potential to provide better thermal comfort, indoor air quality and lifecycle cost savings for today's modern offices. In recent years, with the growing needs of information technology equipment and network, the use of raised-floor construction has attracted much attention in many cities. Combined with an underfloor air system, the raised-floor design can offer an effective solution for offices and commercial spaces. However, concerns about the problem of dust stirring from the floor and the possible discomfort caused by draft and vertical temperature differences still need to be investigated.

(b) ***Desiccant-based cooling systems***

Most mechanical cooling system designs attempt to address both the sensible and latent cooling loads with the same pieces of equipment. This does not have to be the case. Many applications can be addressed through the use of desiccants and other methods to control latent loads. Desiccant-based system is designed to provide cooling without refrigeration (NREL, 2001). In these systems, a desiccant removes moisture from the air, which releases heat and increases the air temperature. The dry air is cooled using either evaporative cooling or the cooling coils of a conventional air conditioner. The adsorbed moisture in the desiccant is then removed (the desiccant is regenerated, or brought back to its original dry state) using thermal energy supplied by natural gas, electricity, waste heat, or the sun. Commercially available desiccants include silica gel, activated alumina, natural and synthetic zeolites, titanium silicate, lithium chloride, and synthetic polymers. Figure 3 gives a simplified schematic of a desiccant-based cooling system. The various system components require electricity to operate, but in general they use less than a conventional HVAC system.

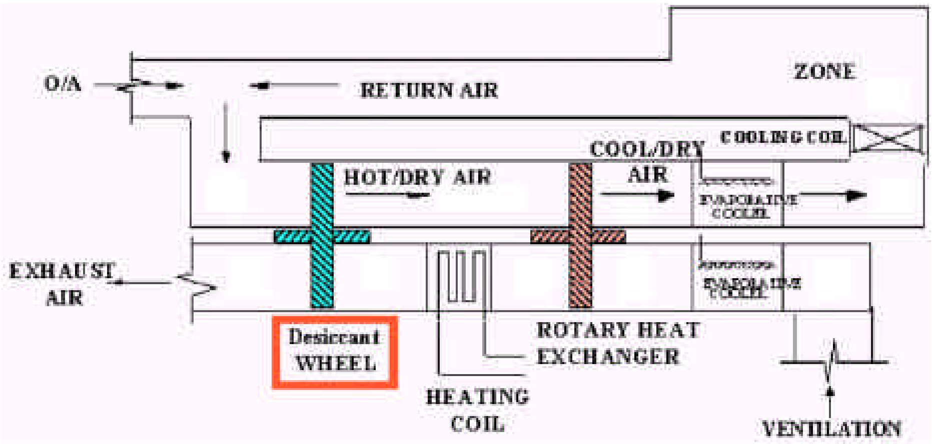

Figure 3 Desiccant-based cooling system

(c) Gas-fired refrigeration plants

Over 90 percent of the mechanical cooling systems in commercial buildings are driven by electricity. However, in urban settings, steam is often available from utility companies to drive absorption machines. Natural gas-fueled chiller systems can provide cost savings in cooling commercial buildings because natural gas is less expensive than electricity per unit of delivered cooling energy. The savings can be especially significant in the summer, when electric rates escalate during high demand periods. Gas cooling is also attractive because gas-fueled systems are designed to operate with refrigerants (water) that are environmentally friendly.

Despite the benefits offered by gas-fueled chiller systems, they often require significant floor space, which is a precious commodity in commercial buildings. There is a need for a gas-powered cooling system with 150 tons or more of cooling capacity that can fit into limited spaces. Natural gas absorption units can only obtain a coefficient of performance (COP) of 1.1. Electric centrifugal units can obtain COPs of up to 6.0. Gas absorption chillers generally cost 1.5 to 2.5 times that of electric chillers and often require larger pump modifications.

(d) Demand-controlled ventilation

Improved detection of pollutants in the building air stream will improve indoor air quality and energy efficiency of the HVAC system, particularly by using advanced sensors and controls technology. Demand-controlled strategies adjust the ventilation rate so that when there is less demand for ventilation (i.e., fewer occupants), less fresh air is supplied to the building in order to save energy. The most common of these strategies provides ventilation air in proportion to the indoor CO_2 concentration. The use of CO_2 sensors that allows for demand ventilation of spaces based on actual occupancy can reduce unnecessary overventilation. However, since these sensors will be used to modulate the amount of outdoor air supplied to occupants, their long-term reliability will be critical. You may encounter resistance to their use by local code officials and others. In general, the greatest savings in electrical usage for cooling with the addition of demand-controlled ventilation occur in situations where the opportunities for economizer cooling are less. This is true for warm and humid climates and for buildings that have relatively low internal gains (i.e., low occupant densities).

(e) Solar cooling and refrigeration

It is possible to use solar thermal energy or solar electricity to power a cooling appliance or a refrigerator. Active solar energy systems use a mechanical or electrical device to transfer solar energy absorbed in a solar collector to another component in the system. There are a few types of the systems now being used or developed, including solar absorption air-conditioning, solar-assisted desiccant cooling, photovoltaic-powered evaporative cooling, photovoltaic-powered heat pumps, air conditioners and refrigerators, and Rankine-cycle heat engine.

The cooling demand and availability of solar energy tend to coincide in most countries. For example, during summers while cooling load increases, the solar intensity also increases. Hence a natural synchrony between the load and the input would be achieved and this can provide a good opportunity for demand-side management. Aside from being a clean renewable energy source, the use of solar energy reduces our reliance on polluting fossil fuels.

6. CONCLUSION

Green building approach enables building owners and managers to reduce energy consumption, improve the work environment, and reduce the environmental impacts of building operations. If the building can reduce operating costs, increase occupant productivity, and decrease health complaints, as well as be environmentally responsible, it is a green building. To ensure this, HVAC systems have an important role to play since many of the green building factors are directly or indirectly affected by the performance of the HVAC systems. An integrated and holistic design process beginning at a project' s inception is required to optimise the HVAC design and operation for green buildings.

A few new HVAC technologies have been used or considered at present. Currently, these technologies are being used successfully in some niche applications, and performance improvements will continue to drive down system costs and accelerate integration of the new systems within conventional HVAC systems. If green means happier tenants and healthier occupancy rates, more building owners would want to incorporate these technologies to gain a powerful market advantage. HVAC and building designers are responsible for bringing this into reality and contributing to the green revolution.

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探討綠建築之暖通空調設計及運作

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摘要: 介紹綠建築的基本概念，討論暖通空調所擔當的角色如何能確保高效能、可持續建築的設計和運作。 闡釋綠色暖通空調的設計要點，以及簡介發展中的技術。

關鍵詞: 綠建築，暖通空調，設計和運作。