Hui, S. C. M. and Li, Y., 2002. Enhancing sustainability of buildings by using underfloor air conditioning systems, In *Proc. of the Chonqing-Hong Kong Joint Symposium 2002*, 8-10 July 2002, Chongqing, China, pp. A113-121. (in English with a Chinese abstract)

Enhancing Sustainability of Buildings By Using Underfloor Air Conditioning Systems

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ABSTRACT

This paper describes the sustainability concept of HVAC systems and discusses how underfloor air conditioning systems can be used to enhance the sustainability performance of commercial buildings. Possible benefits, flexibility and economic issues of underfloor air conditioning are discussed. Important design considerations of such approach are explained. Like many other sustainable features or HVAC technologies, careful planning and holistic design are needed to effectively apply underfloor air conditioning in the building. The benefits of the underfloor approach can be fully recognized when all the influencing factors in the building life cycle are taken into account, including construction costs, life cycle costs, controllability, indoor air quality, and energy performance.

Keywords: Sustainability of buildings, HVAC systems, underfloor air conditioning.

1. INTRODUCTION

Sustainability of heating, ventilating and air conditioning (HVAC) systems has become a growing concern for building owners and building designers (Hui, 2001). Usually, the energy intensity of buildings is mostly in the HVAC systems that create indoor comfort by compensating for outdoor climatic conditions. Sustainability principles and green building performance characteristics are pushing building designers to investigate climate-responsive designs and innovative HVAC systems. New strategies for providing comfort in buildings are progressing rapidly but still have much room for improvement.

A new approach to provide air conditioning in buildings is to make use of a raised access floor for air distribution. This concept of underfloor air conditioning has been studied and implemented in many green or sustainable building projects in a number of countries around the world. Underfloor air conditioning systems are becoming a popular alternative to traditional overhead systems for many office and commercial buildings in Japan, Europe and USA (Matsunawa, Iizuka and Tanabe, 1995; Sodec and Craig, 1990; McCarry, 1998; Terranova, 2001). The use of raised access flooring systems for office environments, whose cavity can be used as a supply air plenum, has become much more frequent in recent years (Loudermilk, 1999). These underfloor air conditioning systems can provide opportunities for improving space ventilation and reducing installation and operating costs.

This paper describes the sustainability concept of HVAC systems and discusses how underfloor air conditioning systems can be used to enhance the sustainability performance of commercial buildings. Possible benefits, flexibility and economic issues of underfloor air conditioning are discussed. Important design considerations of such approach are explained. It is hoped that better understanding of underfloor air conditioning systems can be developed and suitable application of the systems can help enhance the sustainability performance of buildings.

2. SUSTAINABILITY OF BUILDINGS AND HVAC SYSTEMS

Sustainability of buildings covers a wide range of issues including economy of resources, building life cycle design and humane design factors. To achieve sustainable and better performance buildings, it is important to consider the various aspects of building design and their interrelationship holistically and systematically. In most commercial buildings, the HVAC system is a key component determining the quality of the indoor environment and the economy of the building project. HVAC system design is a key feature of sustainable buildings and the equipment associated with climate control, such as fans, pumps, motors, ducts, pipes, etc., significantly affect capital and operating costs, energy use, indoor air quality, and environmental impact. Thus, HVAC systems will greatly impact how “sustainable” or “green” a building is (Hui, 2001).

To enhance the sustainability, consideration of the building life-cycle is vital, as all too often energy-saving and sustainable design features are rejected to reduce capital cost, thereby increasing energy use and total cost of ownership. In addition, pressures to complete projects on time and under budget regularly might produce decisions that are penny-wise but pound-foolish. A good example is the design for flexibility to accommodate future changes in the building. If modular planning and flexible building infrastructures for HVAC are not used due to a higher first cost, then significant penalties in operating costs might be incurred over the whole life cycle of the building.

Sustainable design requires an integrated, whole-systems approach to succeed and innovation is often needed to formulate effective design solutions. But unfortunately, traditional HVAC design process is often separated from architectural design process and many HVAC designers are reluctant to innovation. Unfamiliar approaches, new and more efficient technologies, and innovative designs are frequently rejected lest they slow a project down or increase the risk to one of the participants. To achieve sustainable buildings, it is important to put HVAC design and system selection in a more integrated, open-minded perspective.

3. UNDERFLOOR AIR CONDITIONING SYSTEMS

Underfloor air conditioning systems were introduced first in 1950s in Europe for rooms with high heat loads (typically 190 to 950 W/m^2) such as computer rooms, control centres and laboratories; then later in 1970s, offices in South Africa, Germany, Japan and USA adopted these systems to cope with modernisation and increasing use of electronics equipment. An underfloor air conditioning system is set up based on a raised-access flooring system that is supported on vertical supports approximately 300 to 400 mm above the slab floor. The concept of underfloor air distribution has been implemented and studied in Japan, Germany and USA (Hanzawa and Nagasawa, 1990; Sodec and Craig, 1990; Bauman, Pecora and Webster, 1999). A famous bank building in Hong Kong has also adopted a ducted underfloor air distribution system since 1984.

Another type of underfloor air conditioning is to make use of a plenum space between the structural concrete slab and the underside of a raised floor system to deliver conditioned air into the occupied zone through a variety of supply outlets or terminal units located at the floor level or as part of the furniture and partitions. High-induction swirl diffusers are sometimes used to quickly mix the supply air as it enters the occupied zone. Air is circulated in an upward motion similar to natural convection and is exhausted through return grilles in the ceiling or in the floor.

This “ductless” system is highly flexible and has the potential to provide life-cycle cost savings and better space air quality for today’s modern offices. In recent years, with the growing needs of information technology and network equipment, the use of raised-floor construction has attracted much attention in Hong Kong and other cities. Combined with the underfloor air conditioning system, the raised-floor design can offer an effective solution for offices and commercial spaces. Some high-rise buildings in Hong Kong have used this plenum-based system for underfloor air distribution. To arrange for intake of outdoor air or primary air, either a central or a decentralized primary air handling system can be used (see Figures 1 and 2).

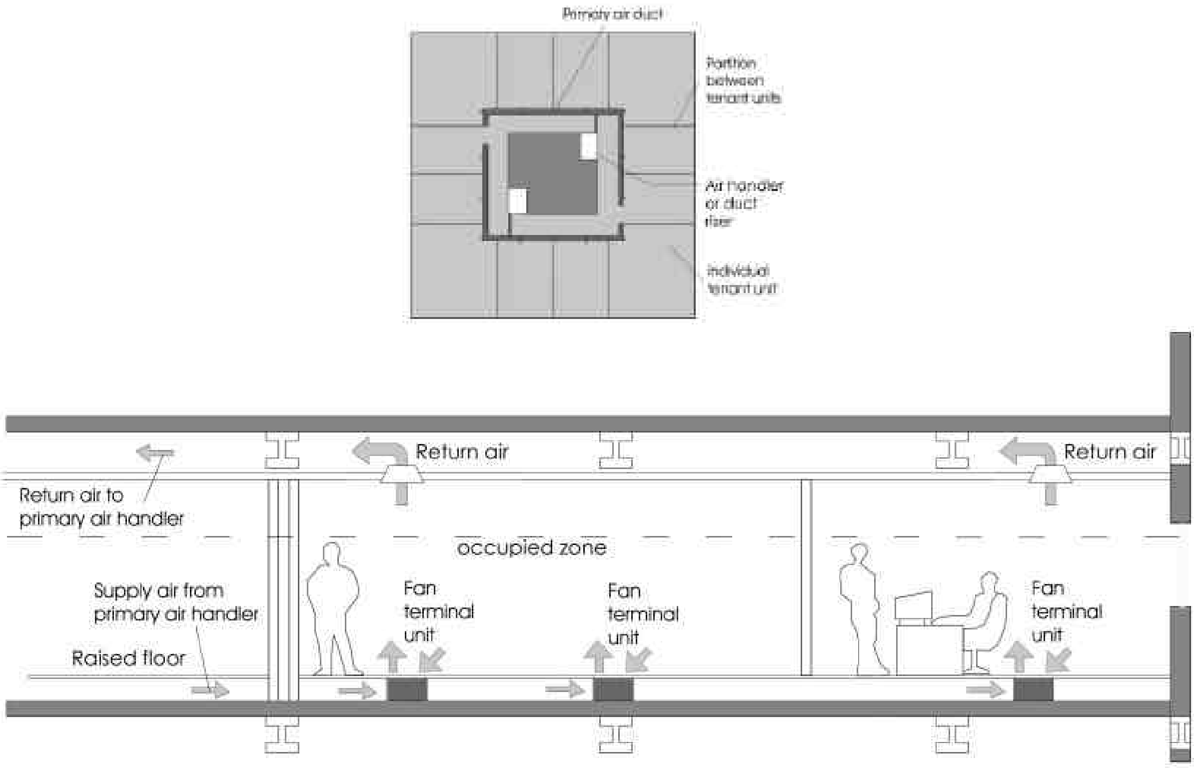

Figure 1. Underfloor air conditioning system with central primary air handler

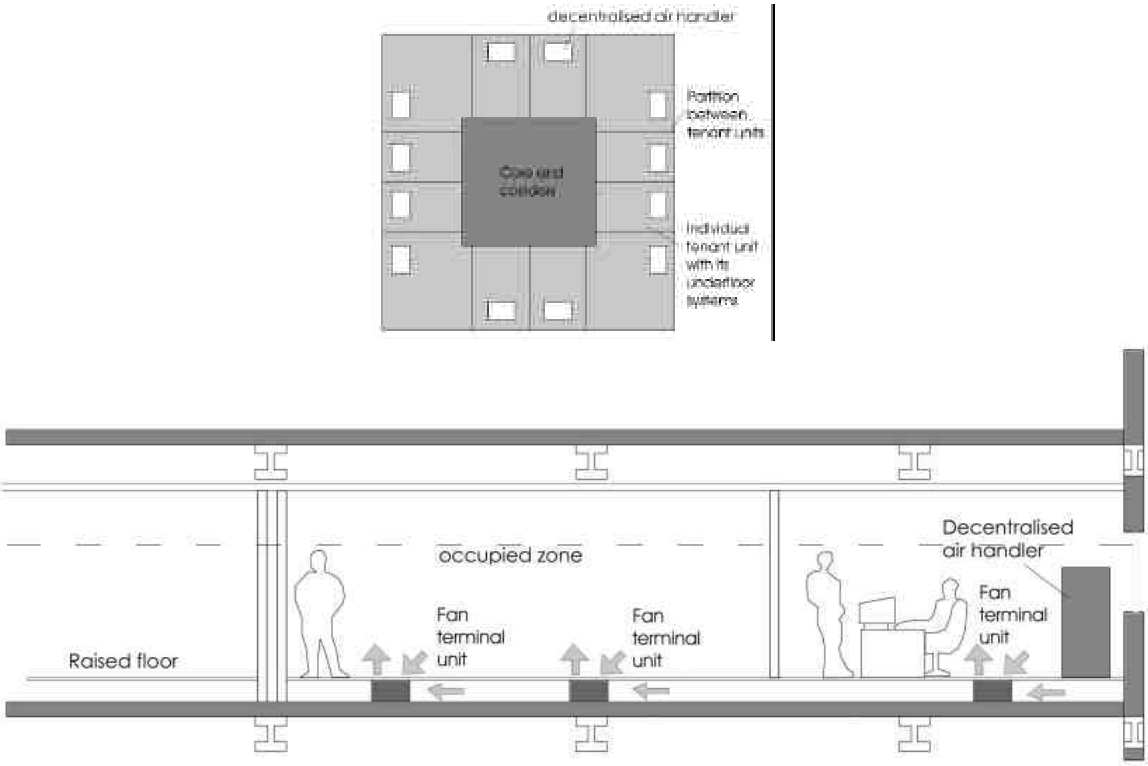

Figure 2. Underfloor air conditioning system with decentralised primary air handlers

To better integrate with the raised floor system, electrical power, telephone, data cable and other portions of the building' s infrastructure are located in the underfloor space. Plug-in electrical boxes, power/data outlet boxes and air diffusers are flush-mounted in the floor panels and can easily be moved to accommodate reconfiguration of the workspace or floor plan. The surface of the floor panels, usually designed in standard modules, can be made of a variety of materials, including carpet tiles, decorative concrete, linoleum, finished metal or wood composite.

4. POSSIBLE BENEFITS

Bauman and Webster (2001) have reviewed and summarised the major benefits of underfloor air distribution as follows:

- reduce life-cycle building costs by improving flexibility in reconfiguring building services and office layout;
- improve thermal comfort, occupant satisfaction and productivity by providing individual comfort control;
- improve ventilation efficiency, indoor air quality and health by delivering fresh air in the vicinity of building occupants;
- reduce energy use from thermal stratification, reduced static pressures, and increased economizer operation; and
- reduce floor-to-floor height in new construction by lowering the height of service plenums.

The key benefits of an underfloor air conditioning system are occupant comfort, energy efficiency and space planning flexibility (Loudermilk, 1999). Occupants can adjust the diffusers to deliver air according to their individual temperature preferences. In addition, the upward flow of low-velocity air reduces lateral mixing compared to a conventional high-velocity HVAC system. By delivering air directly to each workspace, the HVAC system eliminates "dead zones" of air flow. The improved air circulation can further enhance comfort and reduce the concentration of air contaminants at the breathing level of seated occupants.

The supply air of an underfloor system is typically delivered at a higher temperature (16-17º C) than a conventional HVAC system (12-13º C). This increases energy efficiency by extending the hours that the building can be "free-cooled" with 100% outside air. The lower static air pressures (25 Pa vs. 750 Pa) can deliver significant cost savings as a result of downsizing supply air fans. Under the low to intermediate supply air volumes, the performance of an underfloor air distribution system resembled that of displacement ventilation and may inherit some of the benefits of displacement systems like high ventilation effectiveness (Bauman, et al., 1995). Higher air circulation in the conditioned space during part loading conditions will also help to avoid stagnant air and ensure removal of air pollutants at part load. Other benefits of underfloor air distribution systems may include increased chiller efficiency and reduced cooling load requirements.

5. FLEXIBILITY AND ECONOMIC ISSUES

The raised-panel flooring permits a "plug and play" floor design and eliminates the need to hard-wire furniture systems and most walls. The components of the underfloor system are highly modular, making it much easier and less expensive to reconfigure workspaces during renovation of the building. Commonly used floor panels typically weigh only 20 kilograms and are easy to move or replace. The vertical supports, air diffusers, electrical boxes and data boxes can be quickly adjusted or moved by the occupants or the building maintenance staff.

For tall buildings, the most important design and cost implication of the underfloor system is the effect on the height and depth of floor and ceiling void respectively (Smith, 1992). By proper integration of an underfloor air conditioning system into building structure, it is possible for the overall height of service plenums (underfloor and ceiling plenums) to be reduced. Figures 3 and 4 show the sections of a conventional ceiling-based HVAC system and an underfloor air conditioning system respectively. It can be seen that a reduction of 400 mm can be achieved by using the underfloor system.

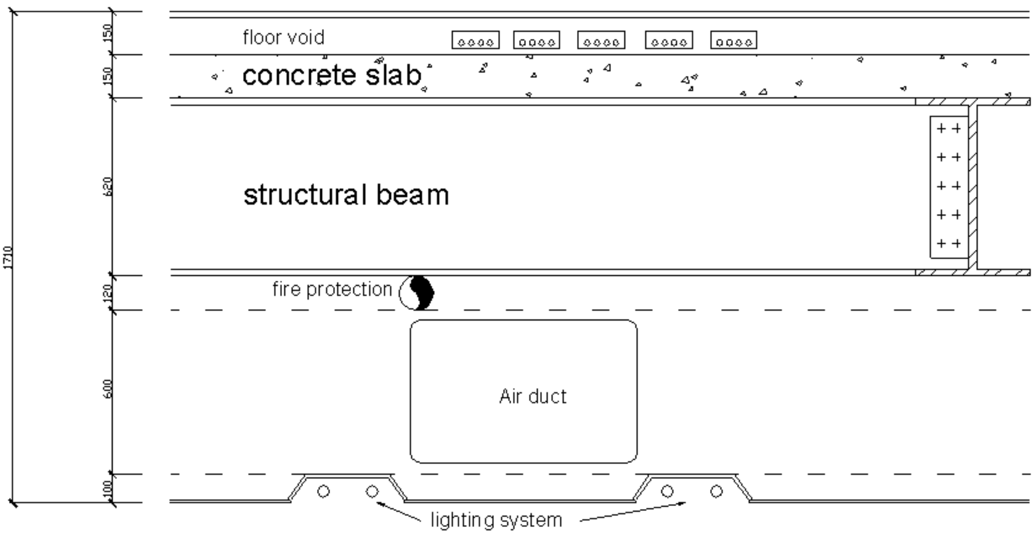

Figure 3. Ceiling and floor voids of a ceiling-based HVAC system

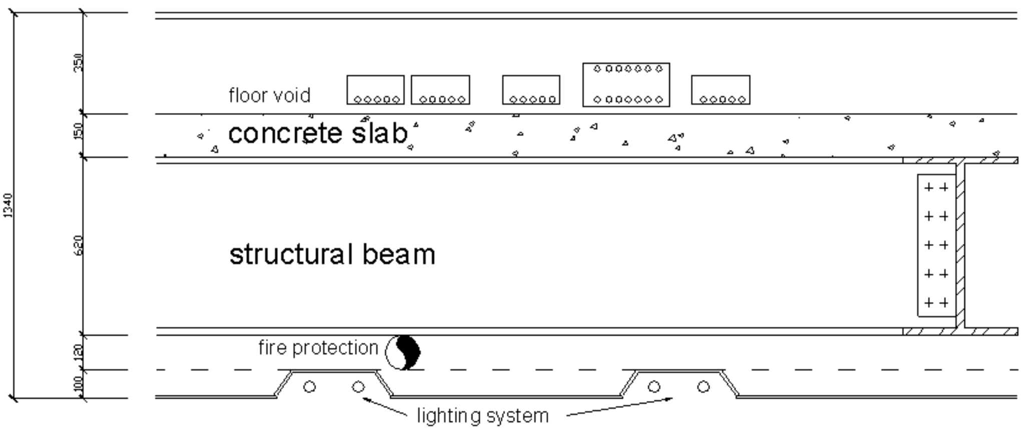

Figure 4. Ceiling and floor voids of underfloor air conditioning system

With much of the HVAC components removed from the ceiling, underfloor air distribution permits a much more open ceiling design, making it easier to include indirect lighting, daylighting, light shelves and other design features in the ceiling. Some designs may even allow the ceiling plenum to be completely eliminated (McCarry, 1995) and this will open up new opportunities for better integration of building structural and services systems. For example, energy and operating cost savings can be achieved by using the concrete floor slab in a thermal storage strategy and by night venting of the floor plenum, but further research is needed to optimise and quantify this effect for different climatic regions.

Compared to a building with a conventional HVAC system, a building with an underfloor air conditioning system in fact can be constructed at a competitive first cost and can operate at a considerably lower life cycle cost. The first cost difference between a conventional ceiling-based HVAC system and an underfloor system can be minimised and in some cases completely offset by savings in installation costs for ductwork and electrical services, as well as from downsizing of some mechanical equipment. It should be noted that the first cost of installing a raised access floor is most commonly justified on the basis of improved cable management. If portions of the underfloor system qualify as a furniture system, they may be eligible for accelerated depreciation too and can reduce the financing cost of the building project.

The flexibility and ease of installing and modifying underfloor systems can also provide a financially attractive point. Experience from some pilot projects in Hong Kong indicated that the speed of installing an underfloor system in new and existing office buildings is faster than conventional duct-based systems. If the time of occupancy and the speed of fitting work are critical financial factors for building owners and tenants, then underfloor systems can provide an efficient solution to speed up the process. Over the whole life cycle of a building, if the frequency of tenants moving in and out is significant, it is expected that underfloor systems can be constructed at a competitive first cost and can operate at a considerably lower life cycle cost.

6. DESIGN CONSIDERATIONS

Underfloor air conditioning systems can be used for whole buildings or portions of buildings, but it is not easy to determine the range of optimal building sizes for application of these systems. Successful application requires an integrated design, making these HVAC systems appropriate for new construction and, in some cases, major renovation of older buildings with high ceilings. Like other HVAC systems, there are both highly appropriate and less than ideal applications. 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.

In practice, the systems have a wide variations of options for configuration when they are applied to commercial buildings. Depending on the actual situation and particular requirements, the design options can be quite complicated and hybrid solutions that combine different systems are commonly used. Table 1 summarises the typical options for the design configurations. For example, a pressurised or non-pressurised raised floor plenum can be employed for the air distribution; central or decentralised primary air handlers can be used (see also Figures 1 and 2); constant or variable air volume can be adopted for the supply air. To select and design an appropriate system, understanding of the operating characteristics of underfloor air conditioning is required. Simply putting an underfloor air conditioning system in a building without proper design and control will not provide the building owner the desirable effects.

Table 1. Design configurations of underfloor air conditioning systems

Description	Options	Remarks
Use of pressurised plenum	Yes or No	Typical 12-25 Pa
Use of non-pressurised plenum	Yes or No	Zero or -ve pressure (-5 to –12.5 Pa)
Use of central air handling units	Yes or No	With or w/o decentralised units
Use of central primary air handling units	Yes or No	For pretreat of outdoor air
Use of decentralised air handling units	Yes or No	Usually located in conditioned space
Use of central fresh air fans	Yes or No	For intake of outdoor air
Use of decentralised fresh air fans	Yes or No	For intake of outdoor air
Supply air through passive floor diffusers	Yes or No	Pressurised plenum is required
Supply air through fan-powered terminals	Yes or No	For non-pressurised systems
Supply air through furniture or partitions	Yes or No	Task conditioning is applied
Supply air volume at air handling units	Constant or variable	Proper control strategy is required
Use of economiser at air handling units	Yes or No	Control by temperature or enthalpy
Return air to air handling units	Thru' ceiling plenum, floor plenum, air duct, or space	Must be separated from supply air
Supply of primary air (from central units)	To decentralised AHU, the space or the plenum	Proper mixing and distribution is important

Underfloor systems can also be integrated with personalised task conditioning based on desktop- or partition-based design. Bauman and Arens (1996) provided an excellent review of "task air conditioning" systems that build on an underfloor approach. In these systems, occupants can individually control the immediate environments within their occupied areas through changing air speed, direction and even air temperatures at the supply registers. Most reported task air conditioning systems to date used underfloor plenums.

At present, design and analysis of underfloor air conditioning systems are not widely understood by practitioners. Loudermilk (1999) pointed out that most load calculation procedures and programs in use today are based on overhead systems, and do not afford the designer the tools necessary to properly assess the performance and economics of underfloor air distribution systems. Therefore, there is a need to establish analysis methods and design guidelines for the underfloor air conditioning systems so as to evaluate their application and optimise their performance.

Moreover, there are a few key design issues that people need to consider when trying to use the underfloor air conditioning systems.

- The perceived higher cost of the systems.
- Concerns about the problem of dust stirring from the floor.
- Possible discomfort caused by draft and vertical temperature differences
- Possible obstructions to the air flow in the raised floor plenum.

7. CONCLUSION

Like many other sustainable features or HVAC technologies, careful planning and holistic design are needed to effectively apply underfloor air conditioning in the building. The benefits of the underfloor approach can be fully recognized when all the influencing factors in the building life cycle are taken into account, including construction costs, life cycle costs, controllability, indoor air quality, and energy performance.

A well-designed underfloor air conditioning system can provide improved thermal comfort, ventilation and indoor air quality, and occupant satisfaction and productivity at first costs and energy use similar or lower than conventional ceiling-based systems. The system has the potential to be applied effectively in new and existing buildings. The flexibility and ability to allow individual control are the key benefits of the underfloor approach.

It is believed that sustainability of buildings can be enhanced by using underfloor air conditioning systems if designers follow sustainable design principles, apply engineering fundamentals in innovative ways, and build confidence based on proven examples. The result will be buildings that are more economical, comfortable, life affirming, and pleasant to be in.

REFERENCES

Bauman, F. S. and Arens, E. A., 1996. *Task/Ambient Conditioning Systems: Engineering and Application Guidelines*, Final Report, October 1996, Center for Environmental Design Research, University of California, Berkeley, CA.

Bauman, F., Pecora, P. and Webster, T., 1999. *"How Low Can You Go?" Air Flow Performance of Low Height Underfloor Plenums*, Summary Report, Center for the Built Environment, University of California, Berkeley, Berkeley, CA.

Bauman, F. and Webster, T., 2001. Outlook for underfloor air distribution, *ASHRAE Journal*, 43 (6): 18-27, June 2001.

Bauman, F. S., et al., 1995. Testing and optimizing the performance of a floor-based task conditioning system, *Energy and Buildings*, 22 (3): 173-186.

Hanzawa, H. and Nagasawa, Y., 1990. Thermal comfort with underfloor air-conditioning systems, *ASHRAE Transactions*, 96 (Part 2): 696-698.

Hui, S. C. M., 2001. HVAC design and operation for green buildings, In *Proc. of the Xian-Hong Kong HVAC&R Seminar 2001*, 11-13 June 2001, Xian.

Loudermilk, K. J., 1999. Underfloor air distribution solutions for open office applications, *ASHRAE Transactions*, 105 (Part 1): 605-613.

Matsunawa, K., Iizuka, H. and Tanabe, S-I., 1995. Development and application of an underfloor air conditioning system with improved outlets for a "smart" building in Tokyo, *ASHRAE Transactions*, 101 (Part 2): 887-901.

McCarry, B., 1998. Innovative underfloor system, *ASHRAE Journal*, 40 (3): 76-79, March 1998.

McCarry, B. T., 1995. Underfloor air distribution systems - benefits and when to use the system in building design, *ASHRAE Transactions*, 101 (Part 2): 902-911.

Smith, M., 1992. Counting the costs, *Building Services*, 14 (2): 26-27.

Sodec, F. and Craig R., 1990. The underfloor air supply system - The European experience, *ASHRAE Transactions*, 96 (Part 2): 690-695.

Terranova, J., 2001. Underfloor ventilation: raised-floor distribution for office environments, *HPAC Engineering*, 73 (3): 37-41, March 2001.

運用地下送風空調系統以提高建築之可持續性能

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摘要: 本論文闡述空調系統之可持續性能概念，討論如何運用地下送風空調系統以提高商業建築之可持續性能。 討論地下送風空調之優點、靈活性能及經濟因素，並詮釋其重要的設計考慮事項。 地下送風方式跟其他可持續建築設計及空調技術相近之處，在於都需要仔細規劃和全面綜合設計，才能更有效地運用。 要發揮地下送風方式的最大優勢，便必須全面顧及會影響建築生命週期的種種因素，當中包括建築費用、生命週期費用、自控能力、室內空氣質素、與及節能效果。

關鍵詞: 建築之可持續性能，空調系統，地下送風空調系統。