HYBRID AIR-CONDITIONING SYSTEM DESIGN USED IN ATRIUM BUILDINGS

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ABSTRACT
The atrium is proliferating, with an increasing frequency, in new, renovated, and converted office and commercial buildings. This paper firstly states the fundamental of stack-driven natural ventilation in atrium buildings. According to its ventilation characteristics and the defect that direct introduction of outdoor air through the windows does not necessarily guarantee the indoor thermal environment within a comfort range, a hybrid air-conditioning system, utilizing cross ventilation and under-floor air conditioning or radiation panel cooling is advised to be used into this kind of buildings. The hybrid air-conditioning system with radiation panel cooling is of more energy efficiency. Finally, the use of cooling system incorporated to a waterscape in atrium is considered, and the measures that fan and filling installations are proposed to improve the heat and mass transfer. However, the heat released from the waterscape should further be investigated, for it may affect the air flow patterns and thermal comfort in the buildings.

INDEX TERMS
Ecological building, Atrium, Stack-driven, Hybrid air-conditioning, Waterscape

INTRODUCTION
According to an investigative report from the American World Observation Institute, sick building syndrome (SBS) exists in about 50 per cent new built or rebuilt buildings. To make building healthy and sustainable, recently ‘ecological building’ is put forward (Saman 1996).

The atrium form was originally used in ancient Greece and Rome, while the origins of the modern atrium can be traced back to the construction of the Hyatt Regency Hotel in Atlanta in 1967 (Sharples. and Bensalem 2001). It becomes a central feature of many modern naturally ventilated building designs. Atriums revive the indoor space by admitting natural light, simulating the outdoors, and increasing people interaction. They have psychological and physiological effects on the sentiments of people.

As so many merits atrium can provide, many researchers have explored this building form from different aspects: Bryn (Bryn 1995) presented a historical development of atriaums and discussed design aspects from the perspective of atrium function, indoor thermal environment and energy use; Landsberg et al. (Landsberg et al. 1986) investigated the impact of a wide range of design strategies on the energy performance of atrium buildings. The design strategies focused on the characteristics of the fenestration and HVAC system and control strategies; Yoshino et al. (Yoshino and Ito 1995) reviewed current atrium research projects in Japan, and identified common trends in the design of the indoor thermal environment and the construction of atrium buildings; Joanne et al. (Joanne et al. 2003) developed a theoretical model to predict the steady stack-driven displacement flow and thermal stratification in the building, due to heat gains in the storey and solar gains in the atrium, and compared with the results of laboratory experiments.

The study of this paper is focused on the ventilation and airflow used in the atrium.

THEORY OF STACK-DRIVEN VENTILATION
In the absence of an external wind field, the stack pressure provides the only natural force to drive a ventilation flow. This basic principle may be understood by considering a space with two small ventilation openings, separated by a vertical height \( h \), as shown in Figure 1.

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According to the equation (1) the sum of the absolute differential pressure value of the incoming and exhaust openings, what we call the ‘thermal pressure’ is a function of the distance $h$ and the air density difference $(\rho_w - \rho_n)$.

Because of thermal pressure, stack effect comes into being—when air in the building warms, it becomes more buoyant than outside air and rises to escape out of openings. The temperature difference of air and the height difference of windows or holes are the necessary condition to achieve natural ventilation caused by thermal pressure (Yijian Sun. 1994).

$$\Delta P_t + (-\Delta P_e) = \Delta P_{ab} + |\Delta P_{ab}| = gh(\rho_w - \rho_n)$$  \hspace{1cm} (1)

The volume flow rate $Q$ of unidirectional flow through an opening of area $F$ depends on the driving pressure drop $\Delta P$ across it (Yijian Sun. 1994).

$$Q = \mu F \sqrt{\frac{2\Delta P}{\rho_n}}$$  \hspace{1cm} (2)

Where, $\mu$ is the discharge coefficient and is determined empirically. The discharge coefficient is a function of the opening geometry and the flow Reynolds number and can vary significantly with the density difference between the air on either side of the opening(Joanne et al. 2003). The flow through the space is maximized when the temperature difference multiplied by the driving stack height $h$ is maximized.

**HYBRID AIR-CONDITIONING USED IN ATRIUM BUILDINGS**

Although the atrium design has been thought of offering great potential to utilize natural ventilation and reduce energy consumption, it was considered an unrealistic target to provide thermal comfort from the nature for 100 per cent of the year. Consequently, the solution is a hybrid or a ‘mixed-mode’ system, aiming to provide thermal comfort as well as energy conservation. Hyunjae et al. (Hyunjae et al. 2004) develop a type of natural and mechanical hybrid air-conditioning system that will maintain a comfortable indoor thermal environment and maintain air quality, while achieving energy conservation by a rational use of natural ventilation, achieved by openings and mechanical cooling. This concept is illustrated in Figure 2.

The cooled air settles down within the lower part of the room, while the hot and humid air passes through the upper region of the room, expelling the heat and contaminants generated indoors. Compared to common air-conditioning system used in offices, the hybrid air-conditioning system can expect to have a tremendous increase in the amount of outdoor air introduced, and this will significantly improve the indoor air quality when using natural ventilation. This was ascertained from field measurements in Liberty Tower at Meiji University, which is located in the center of the Tokyo Metropolitan area in Japan and has equipped with a hybrid air-conditioning system (Hyunjae et al. 2004).

Another similar hybrid cooling system, utilizing radiation panel cooling instead of under-floor air-conditioning has been investigated by Doosam Song et al. (Doosam Song et al. 2004). The hybrid system coupled with radiation cooling would bring significant energy savings compared to a hybrid system coupled with the under-floor air-conditioning. The comfort temperature of the room can be set higher than other conditioning systems because the heat generated by bodies is absorbed by radiant heat exchange with the cooling panels or cooled wall surfaces
The characteristic of this kind of system used in atrium buildings is that it fully utilizes stack forces to generate air flows through the room spaces adjoining the atrium (Figure 3). In summer the stack force can be dominant and the atrium acts as a chimney to vent warm air out of rooftop openings. It can also enhance the flow by dint of the skylight, which can absorb radiation from the sun, and can control its opening area in different conditions.

However, the efficiency of hybrid air-conditioning system depends on the design details of the building composition in providing appropriate airflow pattern to the courtyard, more effort should taken to improve the feasibility of this strategy used in China. This is a positive job that needs the combination effort between the architect and the equipment engineer.

**APPLICATION OF WATERSCAPE INCORPORATING TO COOLING SYSTEM**

Building waterscapes have been highly valued by environmental designers, psychologists, researchers, sociologists, and the general public for their aesthetic qualities, sensory stimulation, social function, and psychological benefits. Besides clearing the around air, improving the microclimate of the surroundings, the flexibility of water is visually intriguing, emotionally soothing or stirring.

If the air-conditioning cooling system is applied to the waterscape, it can beautify the environment, lessen the nuisance of high noise, and reduce the investment in cooling tower at the same time. This is an idea according to the concept of ‘Ecological Building’. To apply the cooling system to the waterscape successfully, abundance cooling water should be supplied to enhance the heat and mass transfer. So the stream configuration like the fountain or the waterfall, which needs a mass of water, jetting high and far should be used. The ideal method can realized through the use of spray nozzle spraying water in the air and lowering the temperature naturally. The feasibility is shown in Figure 4 (Xiao Chen et al. 2003). Water sprayed by the eight nozzles falls into the pond, then column stream composed of droplet-radius bead is formed, where the main heat and mass transfer occurred. As droplets fall down, the water evaporates and convective heat transfer takes place with large amounts of air sucked.

![Figure 2](image1.png)

*Figure 2. Concept of natural and mechanical hybrid air-conditioning system.*

![Figure 3](image2.png)

*Figure 3. Stack-driven ventilation in atrium building*
in, this process is somewhat like the wind cooling tower.

![Figure 4. Droplets water in the air sprayed by nozzles](image)

However, the efficiency is low if it only depend on the droplets cooling in the air naturally, and this kind of cooling system would be meaningless. In order to enhance the cooling effect, a measure is brought forward to increase the air flux and prolong the contact time between the gas and liquid (Xiao Chen et al. 2003). Figure 5 is the schematic of this measure: fan and filling are mounted to the pond. The fan can reinforce the air flux, if the pond is shallow, wind conduit should be introduced in, as shown in Figure 5 (a). The filling is a multi-layered lattice which obstructs the flow of water. This obstruction breaks up the water droplets and increases the contact time of water to air, thereby increasing the heat transfer rate and efficiency of the cooling system.

![Figure 5 Schematic of cooling mass circulatory water](image)

This kind of cooling system has its own advantages in the application to the atrium, such as the waterscape is used commonly in atrium buildings, the shade offered by plants and surrounding structures avoids it from the direct sunlight, etc. By now, however, there is rare such system used in practice. Its property for atrium should be further investigated; maybe the computer simulation and the tunnel experiment should be done to predict its performance. And one should also consider if the heat generated by the system can be another source of buoyancy ventilation or it just destroyed the thermal comfort.

**SUMMARY**

The atrium is one of building types offering great potential for utilizing natural ventilation and reducing energy consumption. Atrium has become much more common as an integral component of building designs over the last twenty years. But till now the main studies were focused on developing design strategies based on its structure parameters. This article embarks on the applications of its composition characteristics combined with mechanical services. It is brought forward the application of hybrid air-conditioning systems and cooling systems combined with waterscapes in atrium buildings. Point out that the hybrid system in atrium makes full use of the natural ventilation driven by stack effect, and solves the contradiction of building energy efficiency with indoor air quality. And the cooling system combined with waterscape is a rare scheme used in practice, it needs further investigated through computer software or experiment tools.
REFERENCES