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# A combined system of chilled ceiling, displacement ventilation and desiccant dehumidification

Xiaoli Hao[a,b], Guoqiang Zhang[a,*], Youming Chen[a], Shenghua Zou[b], Demetrios. J. Moschandreas[a,c]

[a]*College of Civil Engineering, Hunan University, Changsha, Hunan 410082, PR China*
[b]*Department of Building Environment and Services Engineering, College of Energy and Safety Engineering, Hunan University of Science and Technology, Xiangtan, Hunan 411201, PR China*
[c]*Illinois Institute of Technology, Chicago, IL USA*

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**Abstract**

Different types of heating, ventilation, and air-conditioning (HVAC) systems consume different amounts of energy yet they deliver similar levels of acceptable indoor air quality (IAQ) and thermal comfort. It is desirable to provide buildings with an optimal HVAC system to create the best IAQ and thermal comfort with minimum energy consumption. In this paper, a combined system of chilled ceiling, displacement ventilation and desiccant dehumidification is designed and applied for space conditioning in a hot and humid climate. IAQ, thermal comfort, and energy saving potential of the combined system are estimated using a mathematical model of the system described in this paper. To confirm the feasibility of the combined system in a hot and humid climate, like China, and to evaluate the system performance, the mathematical model simulates an office building in Beijing and estimates IAQ, thermal comfort and energy consumption. We conclude that in comparison with a conventional all-air system the combined system saves 8.2% of total primary energy consumption in addition to achieving better IAQ and thermal comfort. Chilled ceiling, displacement ventilation and desiccant dehumidification respond consistently to cooling source demand and complement each other on indoor comfort and air quality. It is feasible to combine the three technologies for space conditioning of office building in a hot and humid climate.


*Keywords:* Chilled ceiling; Displacement ventilation; Desiccant dehumidification; Thermal comfort; Indoor air quality; Energy conservation

## 1. Introduction

Today, as people spend more and more time in buildings than before, indoor air quality (IAQ) and thermal comfort attract increasing attention. Although a definitive quantitative relation between environment and productivity has not yet been established, individuals perform better, more effectively, in conditioned than in untreated indoor air environments [1]. Therefore, a comfortable and healthy indoor environment should improve the occupants' working efficiency. The operation of a heating, ventilation and air-conditioning (HVAC) system is usually required to achieve comfortable indoor conditions by providing sufficient amount of fresh air to the occupied zone to remove indoor generated contaminants and maintain suitable indoor air temperature and humidity by supplying or removing heat and/or moisture to or from the occupied zone. However, HVAC systems often consume large amounts of energy. In other words, comfortable indoor environment is paid by energy consumption because the amount of energy consumed for conditioning indoor environments affects IAQ and thermal comfort. Therefore, it is important to investigate the possibility of attaining improved indoor environmental quality efficiently without increasing energy consumption or indeed decreasing energy consumption.

Different types of HVAC systems have different energy consumption for the same IAQ and thermal comfort. It is desirable to provide each building with an optimal HVAC

*Corresponding author. Tel.: +86 731 8825398; fax: +86 731 8821005.
*E-mail address:* gqzhang@vip.sina.com (G. Zhang).

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**Nomenclature**

| | |
|---|---|
| $q$ | cooling load (W/m$^2$) |
| $T$ | temperature (K) |
| $f$ | rate of chilled ceiling area to floor area |
| $Q$ | volumetric flow rate of air or chilled water (m$^3$/s) |
| $C$ | specific heat of air (kJ/(kg °C)) |
| $W$ | moisture load of unit floor area (g/s) |
| $d$ | humidity ratio (g/kg) |
| $E$ | cooling or heating capacity (W) |
| $A$, $B$, $C$ | experimental coefficients |
| $c$ | contaminant concentration |
| $N$ | power consumption of primary equipment (W) |
| COP | coefficient of performance of chiller |
| $\delta p$ | total pressure rise of pump or fan (Pa) |
| $R$ | portion of cooling load removed by chilled ceiling in total sensible cooling load |
| $P/Q$ | Ratio between the total sensible cooling load and supply air flow rate |

*Greek letters*

| | |
|---|---|
| $\rho$ | density of air (kg/m$^3$) |
| $\eta$ | effectiveness coefficient |
| $\mu$ | contaminant removal efficiency |
| $\omega$ | portion of cooling load removed by DV system in total sensible cooling load of room |

*Subscripts*

| | |
|---|---|
| IA | indoor air |
| CC | chilled ceiling |
| DV | displacement ventilation |
| SA | supply air |
| FN | fan |
| SHR | sensible heat recovery |
| MR | moisture recovery |
| SHE | sensible heat exchanger |
| EC | evaporative cooler |
| CCL | cooling coil |
| HR | heater |
| EA | exhaust air |
| $i$ | any position of room |
| CH | chiller |
| BR | boiler |
| PP | pump |
| $A$–$O$ | air state points |

system, which would provide the best IAQ and thermal comfort for occupants with minimum energy consumption. Many investigators have focused on this topic and a few novel HVAC systems have been proposed and studied [2–8]. Among these systems, the chilled ceiling (CC) system is viewed as a good alternative for conventional air-conditioning system. CC offers several advantages over a conventional air-conditioning system. It is better in thermal comfort, energy consumption, space saving and noise elimination than conventional system due to its energy transfer mainly by radiation and by decoupling heat transfer mechanisms from ventilation. In addition, the relatively high chilled water temperature used by the CC system enables it to use natural cooling or free cooling, thus reducing energy consumption and pollutant emissions. [9,10]. Owing to these advantages the CC system has attracted much attention in recent years [11,12]. However, CC does not control humidity levels. IAQ becomes a problem for CC system due to its decoupling from ventilation. Therefore, an additional ventilation system is necessary when CC is used for space conditioning. Although natural ventilation may be utilized to supply fresh air for air-conditioning the indoor space, mechanical ventilation is usually used to guarantee an energy efficient air exchange rate. Both mixing ventilation and displacement ventilation can be used to supply fresh air. But, displacement ventilation system supplies conditioned fresh air with low air velocity directly to the occupied zone and therefore it provides improved IAQ [3]. Hence, combined with displacement ventilation, a well designed CC system can achieve better thermal comfort and IAQ.

To avoid moisture condensation on the surface of CC the air dew-point temperature should be controlled below the surface temperature of the chilled panel. In order to attain this requirement, a displacement ventilation system must dehumidify the supply air before it is distributed. Conventional air handling units (AHU) are used for dehumidifying supply air. In such conventional AHU the supply air is dehumidified because moisture contained in the incoming air condenses on the cooling coil surface if the surface temperature of the cooling coil is lower than the air dew-point temperature. In the process of dehumidification, air is also overcooled to rather low temperatures. To avoid discomfort caused by cold draft, supply air is often reheated before it is distributed into air-conditioning space and consequently the system consumes excessive energy. An alternative dehumidification approach is the use of desiccant dehumidification, which uses desiccant, absorbent or adsorbent, to remove moisture in air. The rotary dehumidifier, known as the desiccant wheel, is a common type of sorption dehumidifier. With a rotating desiccant wheel air dehumidification is achieved continuously. Since the supply air is not overcooled in the process of dehumidification, reheating the air is not needed. In recent years, desiccant technology is increasingly gaining acceptance from HVAC engineers [13–16]. Moreover results of numerical simulations show large energy savings when CC is combined with desiccant cooling [17].