

# Thermal simulation of a DOAS+CRCP air conditioning system coupled with a floor containing a phase change material (PCM)

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**Abstract.** The phase change materials(PCMs) is an excellent means for cooling application in buildings to stabilize the indoor air temperature variation due to solar and internal gains and therefore reducing the size, operating time and stress of mechanical systems. This work studies the use of radiant systems for discharging heat stored in a PCM: a PCM is incorporated into the floor, and a Ceiling Radiant Cooling Panel(CRCP) combines with Dedicated Outdoor Air System(DOAS) is used as the energy discharge system. The advantages and disadvantages of this configuration in terms of cooling energy demands and thermal comforts of occupants are analyzed using the simulation software TRNSYS. This simulation reveals that this configuration can significantly improve the degrees of occupant comfort and reduce the cooling energy demand.

## 1. Introduction

Phase change materials( PCMs) can store large amounts thermal energy in latent form in combination with rather small temperature changes<sup>[1]</sup>. This property makes PCMs a perfect means for stabilizing the indoor air temperature close to the set point, thus providing more comfortable conditions in the room.

Radiant systems have long attracted the interest of many researchers and designers<sup>[2]</sup> due to their capability of providing high thermal comfort levels and energy saving with higher water temperatures for cooling applications. However, a number of key issues remain to be addressed before successful implementation of this solution in practical applications can be realized<sup>[3]</sup>: 1) difficult to provide adequate thermal mass within a thin and lightweight ceiling panel and sufficient heat storage capacity to meet the peak cooling load with small space requirements; 2) in hot and humid regions, fears for the risk of condensation on radiant panels. To solve these problems, some researchers propose to integrate the Dedicated Outdoor Air System (DOAS) with the chilling ceiling cooling panel (CRCP) system<sup>[4]</sup>. This system uses 100% outside air with a minimum air flow rate for ventilation integrated with ceiling radiant cooling panel (CRCP), to remove sensible loads.

## 2. Project introduction and HVAC system design

### 2.1 The cooling load calculation of the prototype house

In this study, a typical room chosen from a typical office building in Wuhan is used as the prototype house. The dimension of the office is 5.2m×5.5m×3.45m (width×depth×height), as shown in figure 1.



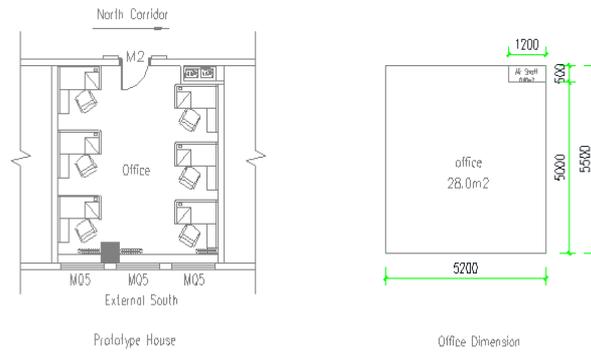


Figure 1. Dimension of prototype house

The TRNSYS software has been used for the cooling load calculation. The simulations include the months between June and September, which has been considered as the cooling demand period in the Chinese residential sector. Table 1 presents the design information of the HVAC system according to the guidelines of design handbook of China [5]. Table 2 presents the setting of internal gains about occupants, computers and artificial lighting based on the real situation.

Table 1. Design information of the HVAC system

	Indoor Air Set Point For Cooling	Climatic Design Data For Cooling
Dry Bulb Temperature (°C)	35.2	26
Wet Bulb Temperature (°C)	28.4	—
Relative Humidity (%)	—	60
Wind Velocity (m <sup>2</sup> /s)	2	0.3

Table 2. Design Information About The Internal Gains

House type	Degree of activity	Occupant Density (m <sup>2</sup> /p)	Equipment power (W/m <sup>2</sup> )	Artificial lighting (W/m <sup>2</sup> )
Office	Seated, light work	0.2	30	10

Figure 2 plots the result of the cooling loads calculation of the office. The maximum cooling load appears on July 23rd, about 5 o'clock p.m., and the maximum cooling load is 2.274kW.

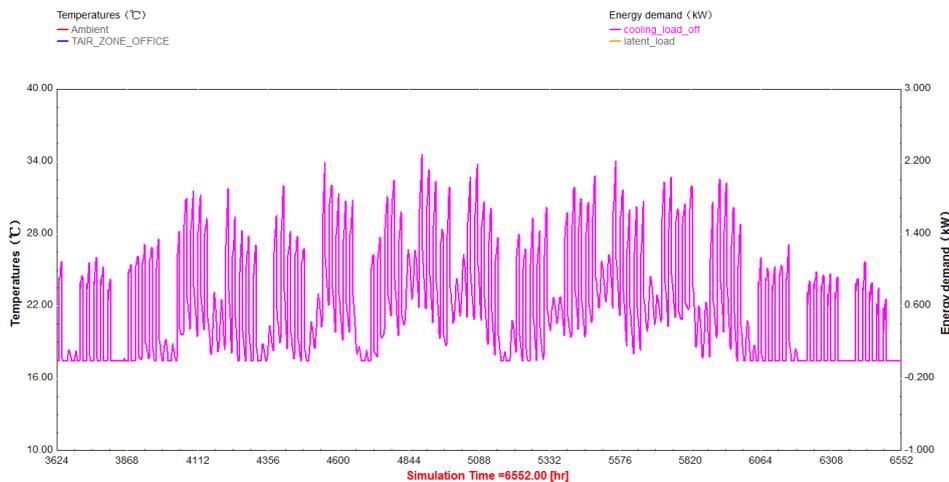


Figure 2. The load calculation results of the office

## 2.2 The design of the HVAC system

The HVAC system combines a fresh air handling unit, chilled ceiling system, and a PCM incorporated floor. According to the design handbook [5], the minimum requirements of the fresh air per occupant is recommended at  $30\text{m}^3 / (\text{h} \cdot \text{p})$ , so the total fresh air requirement of the office  $G_f = 30\text{m}^3 / (\text{h} \cdot \text{p}) \times 6\text{p} = 180\text{m}^3/\text{h}$ . Then the sensible loads accommodated by the fresh air can be derived from Eq. (1):

$$Q_f = \frac{1}{3.6} \times 10^{-3} \cdot \rho G_f (h_N - h_o) \quad (1)$$

Where  $Q_f$  is the sensible loads accommodated by the fresh air, kW;  $\rho$  is the air density,  $\text{kg}/\text{m}^3$ ;  $G_f$  is the fresh air flow rate,  $\text{m}^3/\text{h}$ ;  $h_N$  is the enthalpy of outdoor air;  $h_o$  is the enthalpy of supply air,  $\text{kJ}/\text{kg}$ .

Based on the above calculation, the sensible loads accommodated by the fresh air is 0.786 kW, and the CRCP system accommodate the rest part of sensible loads, which is about 1.5kW.

The CRCP chosen for this study is a metallic water panel. To implement the chilled ceiling within the simulation program, the data required to define the performance under the test condition according to DIN4715-1 standards comprise both geometrical and technical parameters that must be obtained from the manufacturer [6]. Table 3 presents the parameters of the CRCP.

Table 3. Ceiling radiant cooling panel parameters according to DIN715-1 standards

Ceiling radiant cooling panel	
Area/radiant panel	2.5 $\text{m}^2$ (2.5m×1m)
Number of loops	7
Total ceiling panels area	28.6 $\text{m}^2$
Pipe spacing	20 mm
Pipe inside/outside diameter	2.7 mm/4.3 mm
Specific heat coefficient of water	4.18 $\text{kJ}/\text{kg}\cdot\text{K}$
Design $\Delta\theta$ mean water/room air temperatures	7.5 K
Water mass flow/loop	20.7 $\text{kg}/(\text{h} \cdot \text{m}^2)$
Specific norm cooling capacity	60.9 $\text{W}/\text{m}^2$
Heat transfer coefficient according to norm	101.66 $\text{W}/(\text{m}^2 \cdot \text{K})$

## 3. Modeling and simulation of the building and HVAC system in the TRNSYS environment

For this study, the program TRNSYS [7] is used due to its ability to model detailed radiative exchange and occupant comfort and to evaluate the influence of the walls, ceiling and floor containing PCM on the overall energy performance of buildings.

In order to model thermal behavior of PCMs which is a material with non-constant thermophysical properties, a new component Type 204 has been developed. The implementation of this modeling concept in the TRNSYS interface is shown in figure 3.

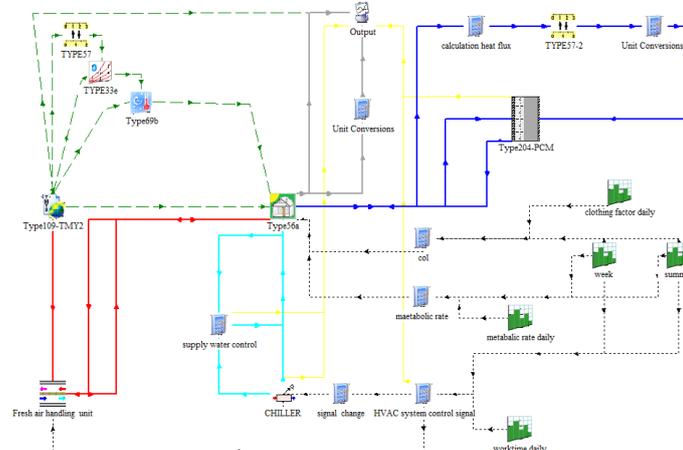


Figure 3. Simulation layout of the facility using the TRNSYS interface

**4. Results and discussion**

Two building models of the prototype house are built in the TRNSYS environment. The first model corresponds to a prototype house in which the desired indoor conditions are maintained by a chilled ceiling system. In addition to these systems, the second model incorporates a PCM in a layer in the floor.

Figure 4 presents the indoor air temperatures and PMV index of the room without PCM layer during two weeks in July. Figure 5 presents the same information of the room with PCM layer.

For the case without PCM, the PMV index oscillates from warm (PMV=+2.67) to slight cool (PMV=-1.5), indicating that the room is a more oscillating environment. Between 8 am to 10 am, which is peak commuting hours, the room temperatures rise extremely fast even when the cooling panels have already turned on. This relative high temperature can cause some degradation of the comfort levels since the occupants may perceive the indoor environment as slightly hotter. In contrast, the room with the PCM layer performs a more comfortable environment (-1.5 ≤ PMV ≤ 1.5). The floor with the PCM layer acts as an effective heat sink/source to maintain the indoor conditions, thereby providing a better comfort levels.

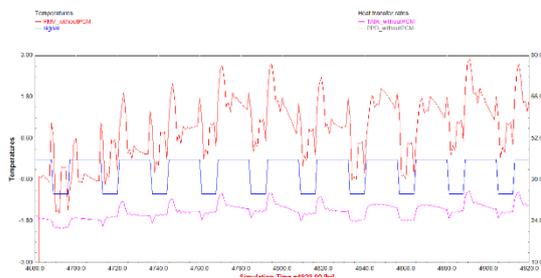


Figure 4. The air temperatures and PMV index of the room without PCM layer



Figure 5. The air temperatures and PMV index of the room with PCM layer

Performing a heat balance on the inner surface of the floor, the net heat flow  $Q_n$  is:

$$Q_{n,floor} = Q_{so,floor} - Q_{co,floor} \tag{2}$$

Where the first term on the right side of the equation,  $Q_{n,floor}$ , is the total solar radiation absorbed and transmitted at the inside surface of the floor. This term can never be negative because the flux direction is always from the outside to the inside of the wall. The second term,  $Q_{co,floor}$ , is the energy from the inside surface of the floor to the zone air including convection and long wave radiation. This term can be positive or negative depending on whether the temperature of the internal surface of the floor is higher or lower than the mean radiant temperature of the surfaces “seen” by the floor.

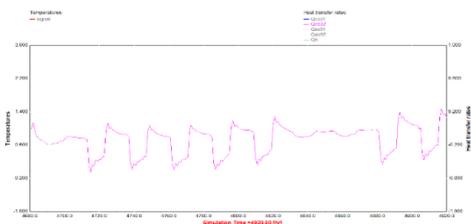


Figure 6. Heat exchange  $Q_{co,floor}$  of the floor with a PCM layer

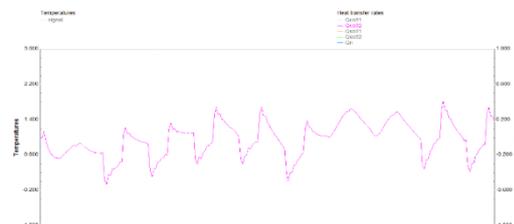


Figure 7. Heat exchange  $Q_{co,floor}$  of the floor without PCM layer

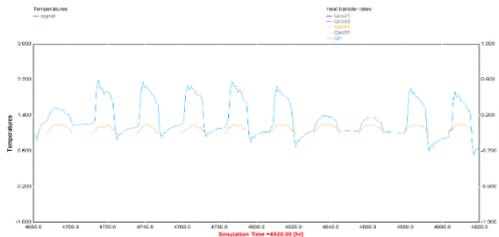


Figure 8. Net heat transfer  $Q_{n,\text{floor}}$  into the floor with a PCM layer

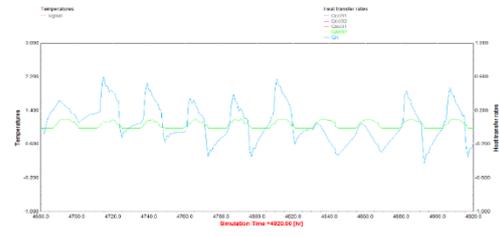


Figure 9. Net heat transfer  $Q_{n,\text{floor}}$  into the floor without PCM layer

The floor with a PCM layer performances a more consistency on heat transfer between the internal surface of the floor and the zone air. The PCM layer can store large amounts thermal energy when the air is cooler and release when the air is hotter, buffer portions of the energy transfer within the building, hence stabilizing the room temperature and reducing and shifting peak cooling loads during summer.

## References

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