Application of Heat Pipes to Displacement Ventilation/Chilled Ceiling Systems

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1. **Introduction to S & P Coil Products Limited**

SPC is a specialist manufacturer and supplier of fan convectors, coil heat exchangers, and HVAC equipment to the public and private sector.

SPC leads the way in HVAC technology and in responsiveness to customer needs. We thrive on innovation, on new technologies and new challenges. We stand for irresistible quality, exceptional customer care, and whole-life value for money.

For more than 20 years, we've applied our ingenuity to the heating, cooling, and dehumidifying of indoor environments – and to the delivery of HVAC equipment that withstands the grind of daily use. The result is a range of products that are aesthetic, robust, and economical to run.

But new ideas aren't developed in isolation. They come from a service culture that takes pride in putting customers first. We listen and, if asked, we advise; we offer free site surveys – and we always return your calls.

Our mission is simple – to become your first-choice HVAC supplier, and to be the one company that provides a solution that exactly matches your needs.

Key facts about SPC:

- Our mission is to be your first choice for HVAC equipment
- Major supplier to local government and commercial sectors
- Unrivalled regional sales and technical support team
- Free site check / survey
- ISO 9001 and Investor in People
2. Executive summary

This application note introduces the concept of displacement ventilation. It highlights the pertinent differences between this form of ventilation and conventional (mixing) ventilation along with the advantages and disadvantages of the competing systems.

Typical design conditions are discussed along with the use of chilled ceilings as a means of supplementing the cooling that is provided by the displacement air.

The pitfalls that can be associated with the combination of displacement ventilation and chilled ceilings are examined and an energy efficient solution utilizing heat pipe technology fully described along with its attendant energy savings.
3. Application notes

3.1 Displacement Ventilation and Mixing Ventilation

Ventilation is the introduction of outside air (primary air) to a space while polluted internal air is extracted.

Traditional methods of ventilation (mixing ventilation) involve the introduction of a mixture of treated outside air and recirculated indoor air at high level outside the occupied zone. This air will be cold at typically 12 to 15°C and supplied at relatively high velocity. Air needs to be cold so that when combined with the relatively high air volume it will offset the internal heat gain. A relatively high velocity is required so that the air mixes with the indoor air effectively outside of the occupied zone. The supply air will typically leave the supply diffuser at 1 to 1.5m/s. Figure 1 shows a conventional mixing ventilation/air conditioning system.

![Figure 1: Conventional mixing ventilation](image)

Conventional air conditioning systems can be either a) all air systems i.e. variable air volume, constant air volume or b) air-water systems using fan coil units. In all air systems the space cooling is provided by the supply air from the central AHU whereas an air-water system provides outside air from the central AHU and local cooling via the chilled water fed to the FCUs. The primary air can be mixed with room air at the FCU, or alternatively, fed via a separate supply. FCUs can provide both sensible and latent cooling to a space, whereas in all air systems all the latent cooling must take place at the central AHU. Displacement ventilation/chilled ceiling systems are a special case of an air-water air conditioning system where the space cooling equipment must do no latent cooling.
Displacement ventilation differs from mixing ventilation as follows:

1. Air is introduced at low level directly into the occupied zone.
2. Air is introduced at relatively warm temperatures, typically 18 to 19°C.
3. Air is introduced at low velocity.
4. Supply air volumes are low and only include treated outside air.

The theory behind displacement ventilation is:
Air that is colder than the space (around 3°C colder) is supplied at floor level into the occupied zone. Being colder than the space air it is more dense and displaces the space air above it.

When the cool, dry displacement air comes into contact with sources of heat and moisture it is warmed and becomes more humid. The effect is to form plumes of low velocity air around people and equipment, cooling them directly and transferring their heat and moisture upwards. See figure 2.

![Figure 2: Displacement ventilation](image)

It has been suggested that mixing ventilation is responsible for distributing contaminants associated with the room fabric and occupants whereas the plumes of warm air typical of displacement systems are unpolluted and result in the contaminants collecting at ceiling level where they are extracted. Accordingly, displacement ventilation results in a healthier environment than mixing ventilation.
Because the air is introduced at floor level it needs to be at a comfortable temperature i.e. 18 to 19°C. It must also be supplied at a low velocity so as not to create uncomfortable draughts.

When the low supply air volume is combined with the relatively high supply temperature the amount of cooling that can be achieved using only the displacement air is limited and typically accounts for only 25% of the total space cooling load. The cooling that is provided by the ventilation air is referred to as primary cooling.

A further source of cooling (secondary cooling) needs to be provided. When using displacement ventilation the low air velocities give rise to stratification, warm polluted air gathering at ceiling level. To counteract this the displacement ventilation system is always combined with a chilled ceiling and high level extract system.

3.2 Chilled Ceiling

A chilled ceiling can consist of chilled beams, chilled panels or a combination of both. Beams are normally found around the perimeter where solar gains are high, panels can be used in the interior of the zone where heat gains are low.

Beams can be passive; relying on warm air to convect over the chilled fin surfaces, or active using low powered fans or induction units. As the air is cooled by the beams/ceiling it must not come into contact with surfaces which are below the dewpoint of the air. If it did then moisture would start to condense onto the ceiling and eventually drip into the room.

For the chilled ceiling to achieve the necessary cooling it must be fed with chilled water at a sufficiently low temperature, while still being above the dewpoint of the air which comes into contact with it. The water to the chilled ceiling is typically supplied at between 14 and 16°C.

Assuming that the dewpoint of the displacement air increases by 1°C as it picks up moisture between the floor and ceiling, it is typically supplied at a dewpoint of 2°C below the temperature of the chilled water feeding the ceiling.
3.3 Application of Heat Pipes

All displacement ventilation/chilled ceiling systems work against almost identical sets of conditions, with the volume of outside air being determined by the size and usage of the space or the level of occupancy. These conditions are:

- Supply air volume: Typically 20 litres/s/person
- Supply air temperature: 18°C
- Supply air dewpoint: 12°C
- Chilled beam water temperature: 14°C

In order to achieve the supply conditions given above, the outside air must be overcooled to remove the moisture, before being reheated to the comfortable supply temperature of 18°C.

Conventionally this process is achieved by over sizing the cooling coil to reduce the air to 12°C in a saturated state then reheating to 18°C using LPHW, steam or electric reheat. This process is energy consumptive. By wrapping heat pipes around the cooling coil both total cooling and reheat requirements will be reduced or eliminated.

So called ‘wrap-around’ heat pipes are used in this application, fitted around conventional cooling coils. Heat pipes are extremely effective conductors of heat due to their internal construction. They absorb heat at their warmer end and transfer it to their cooler end with only negligible temperature differences along their length. Visually, the heat pipes mimic the cooling coil around which they are wrapped consisting of bundles of heat pipe tubes expanded into continuous fins. The face size of the heat pipe will match that of the cooling coil.

The warp-around heat pipe absorbs heat from the air entering the cooling coil and transfers this heat to the air leaving the cooling coil. This process effectively precools the air prior to it reaching the cooling coil and reheats the air after it leaves the cooling coil. The precooling effect and reheat effect are equal and eliminate or reduce the costly overcooling and reheating associated with a conventional system.

Typical design conditions for a displacement ventilation heat pipe system are as follows:

- Outside air: 29.0°C dry bulb/20.0°C wet bulb
- Air off Precool: 23.0°C/18.0°C
- Air off Cooling Coil: 12.0°C/11.8°C
- Air off Reheat: 18.0°C/14.2°C

These conditions are plotted on a psychrometric chart in figure 3 (see page 12).
Figure 3: Psychrometric process
Based on the above conditions the savings accrued through the addition of heat pipes are:

- **Precool saving:** 7.2kW per cubic metre outside air
- **Reheat saving:** 7.2kW per cubic metre outside air

At design conditions the heat pipe will provide all the necessary reheat. Below this condition the reheat needs supplementing by either a conventional reheat coil or, by using a heat recovery heat pipe between supply and extract decks, utilising the heat from the extract air.

A heat recovery heat pipe will typically be a straight heat pipe with its lower end in the warm extract air and its upper end in the cool supply air. This device will then transfer waste heat from the extract air to the supply air so as to provide the necessary reheat free of charge. Figure 4 and 5 (see below) gives details of AHUs with and without the heat recovery device.

![Figure 4: AHU schematic with heat recovery heat pipe](image1)

![Figure 5: AHU schematic without heat recovery heat pipe](image2)
4. **Concluding remarks**

1. Displacement ventilation is more energy efficient than conventional systems as it involves treating relatively low volumes of only outside air.

2. Displacement ventilation directly cools people and equipment, the warm, moist plumes of air gathering at the ceiling.

3. Displacement ventilation systems are healthier than mixing ventilation systems as contaminants are not distributed in the space but concentrated at ceiling level were they are extracted.

4. Chilled ceilings are used to supplement the cooling available from the displacement air.

5. Humidity of the displacement air must be controlled to prevent the ceiling from dripping.

6. Outside air must be treated to remove moisture and provide a comfortable temperature for supply into the occupied zone. Heat pipes allow the most energy efficient means of conditioning the outside air in this fashion.

7. Both ‘wrap-around’ heat pipes and heat recovery heat pipes can be utilised to give a complete solution irrespective of the external conditions and without the need for costly conventional reheat.