A CEILING CONDENSING UNIT WITH PELTIER ELEMENTS FOR DRYING AND COOLING

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ABSTRACT

A condensing device allows to avoid condensation on cooling ceilings in rooms with humid air. It uses thermoelectric modules in contact with the cooling panels. The pumped heat is transferred into the cooling ceiling to keep its temperature above the dew point. Tests have been performed in a full-scale chamber. A set of condensing units was mounted on a standard hydraulic cooling ceiling. The control of temperature is achieved by regulating the mass flow of the water. By this method the loss of efficiency of the cooling panels is fully compensated. Without the condensers, the temperature of the water would have to be increased. This would cause 12 % less cooling power. But with the condensers, the total cooling power is 9 % higher in comparison to panels - without condensers - which are operated in dry air. Finally, we can state that the cooling power is increased by 20 % due to the condensers. If the system is sized to replace the entire (convective) air conditioning system, the following advantages are obtained:

- No noise
- Perfect adaptation to building retrofits (no air ducts, only water piping)
- Less restriction on window opening.

KEYWORDS

Cooling ceiling, chilled panel, condensation, protection, dehumidifier, drier, thermoelectric cooling

PURPOSES OF RESEARCH

Nowadays it is well accepted that radiant cooling ceilings provide a better comfort and normally cause a smaller energy demand than conventional convective air conditioning systems [1, 2, 3, 4]. Furthermore, hydraulic systems require less space, because water has a much higher heat capacity than air [1].

These systems allow to cool the ambient air but not to reduce its vapor content. As long as the temperature of the air is lower than that of the skin, human beings are only weakly sensitive to humidity in a large range (30 % to 80 % relative humidity). For example, Figure 1 shows the thermal comfort calculated according to ISO 7730 [5] versus the difference of temperature between the air and the wet bulb temperature for a given enthalpy density. For all the three cases, which have been calculated, optimal comfort is achieved (PPD of 5 %). The lowest energy cost is obtained for the highest enthalpy density (60 kJ/kg). This is the case where the temperature of the air - at which optimal comfort is obtained - is closest to saturation. The efficiency of cooling panels is clearly limited by avoiding an occurrence of condensation.

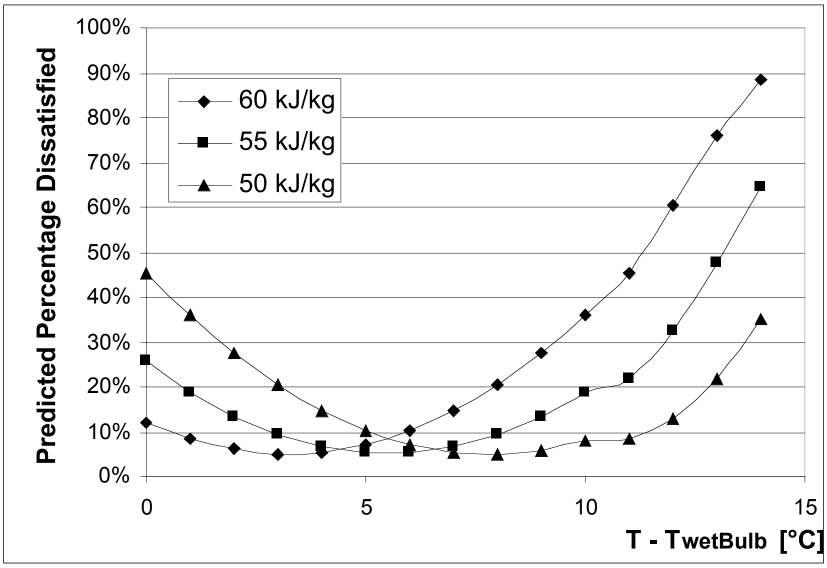

Figure 1 Thermal comfort versus condensation risk for different air enthalpy densities.

As a consequence, cooling panels are only seldom taken into operation without a control of the air condition. The objective of this study is to obtain first experiences with a prototype of a ceiling thermoelectric condenser.

THE METHOD OF APPROACH

The set-up forces condensation to occur only on a limited surface area. Each condensing unit consists of a heat exchanger, which is cooled by Peltier elements. These are in contact with the ceiling panels, to keep the condensing unit at a low temperature (see Figure 2). Therefore, the pumped heat is transferred into the cooling fluid, and the units can be used to maintain the temperature of the panels above the dew point in the downstream direction.

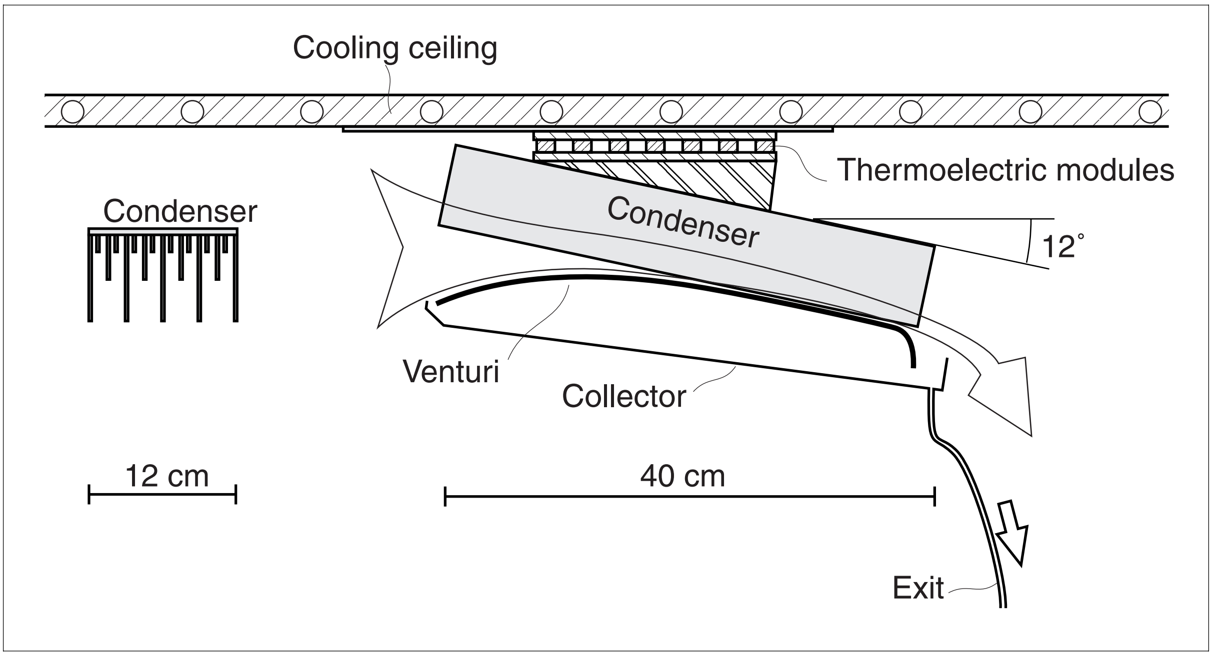

Figure 2 Schematic drawing of a condensing unit (prototype)

Figure 3 A condensing unit in operation

Condensers are aluminum radiators with fins (Figure 3). Their total area of condensation is ten times larger than the area on which they are fixed to the ceiling. A Venturi nozzle accelerates the air in a natural manner without applying any forcing of the air by ventilators. Showing no moving parts, the set-up is very reliable in operation and well-adapted to a seasonal utilization. A tray is placed underneath the device, in order to collect the condensate. A request for an European patent has been deposited, including different possible implementations, especially regarding the removal of the condensed water [6].

A prototype was built and mounted on a cooling ceiling of 12 m^2 area, composed by conventional cooling panels. Tests have been performed in a full-scale climatic chamber (4m x 4m x 3m). The system consists of two times six identical small units, which are symmetrically distributed on two lines (see Figure 4). One line is close to the water inlet and the other to the outlet of the ceiling. The units cover only 4% of the area mounted with cooling panels.

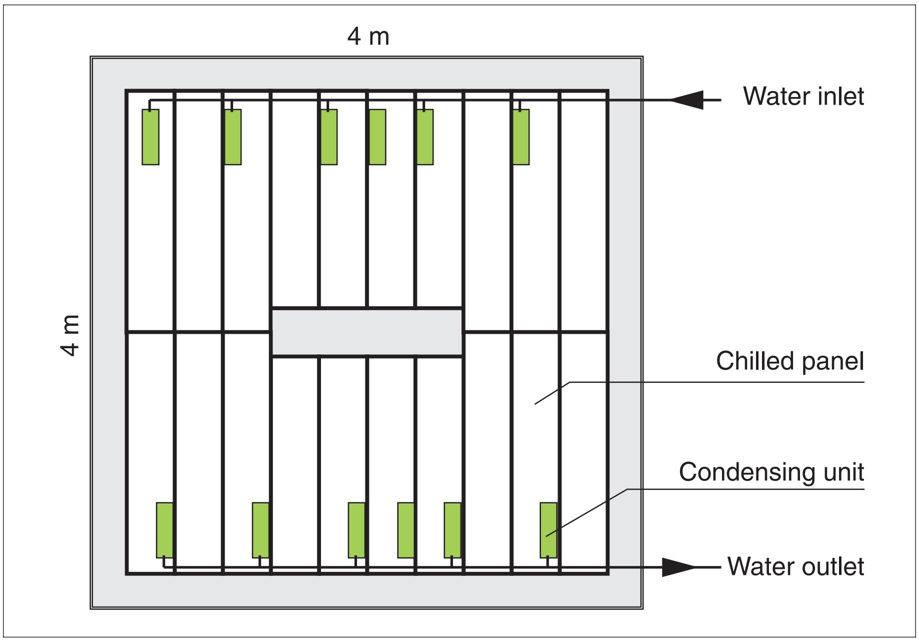

Figure 4 The set-up in the testing chamber

RESULTS AND ASSESSMENT OF THEIR SIGNIFICANCE

Six heaters, releasing a total heat of 930 W, were mounted in a test chamber in order to simulate thermal charges. The worst climatic outdoor conditions met in Lausanne (Switzerland) are reproduced: air inlet temperature 24 °C and relative humidity 80 % (dew point at 20.4 °C). The renewing air rate is set at six volumes per hour, which is high above the hygienic required minimum. The temperature of the water at the inlet is kept at a usual condition, namely 15 °C. A control of the temperature is achieved by regulating the mass flow through the panels.

The main objective - of avoiding condensation on the panels - is clearly achieved. Enough heat is transferred into the ceiling. Measurements show that the loss of efficiency of the cooling panels is compensated by the condensing units. The total cooling power of the combined system - consisting of cooling panels and condensing units - is 9 % higher, compared to the cooling power of the panels, which are operated without condensing units in dry air. Without a protection system for condensation, the temperature of the water would have to be increased. This would cause a reduction of the cooling power of 12 %. Finally, we can state that the cooling power is increased by 20 % as an advantage of the condensing system.

The drying performance of each line of condensers has been measured. At the inlet the amount of condensed water is three times higher compared with the outlet. The performance of the condenser per unit of horizontal cross section is the following:

TABLE 1
Flux density for a difference of ten Kelvin between the water in the unit and the chamber

Pumped heat	520 W m^{-2}
Condensation	175 g h^{-1} m^{-2} (23 % of the pumped heat)

The heat pumped by each module was calculated using to the following equation:

$$\dot{Q}_C = S \cdot T_C \cdot I - R \cdot I^2 / 2 - K \cdot (T_H - T_C)$$

This equation has three measured inputs:

- I : Injected electrical current
- $T_{C,H}$: Temperatures on the cold and hot sides

The resting three parameters are characteristics of the thermo-electrical modules (data provided by the supplier):

- S : Seebeck coefficient
- R : Electrical resistance
- K : Thermal conductance

This model was validated experimentally by changing the number of modules per unit.

The coefficient of performance (COP) is the ratio of the pumped heat to the electrical consumed power, which is assessed by measuring in add the voltage at the terminals of the two lines of units. In steady state, the obtained value for the line at inlet is $COP = 2$.

The flux density of pumped heat is five times higher than that achieved with standard radiant panels mounted on the ceiling. This ratio is still above three when comparing to panels fitted up with fins to reinforced natural convection.

TABLE 2
Comparison with diverse types of panels for ceilings

Type of panel	Performance ratio
Radiant (standard cooling ceiling)	5.7
Reinforced convective effect	3.5

In the present study the air inlet condition corresponds to an extreme weather condition in Switzerland. If the power of the device is increased, the performance of the condensing units can be further extended.

VERTICAL SPACE REQUIREMENT

A high vertical space requirement causes high costs. Air ducts of conventional air conditioning systems take a minimum height of 30 cm per story, which equals approximately 10% less building profitability. The present system is of greater advantage, if it completely can substitute the air conditioning system. Such a solution is shown in Figure 5.

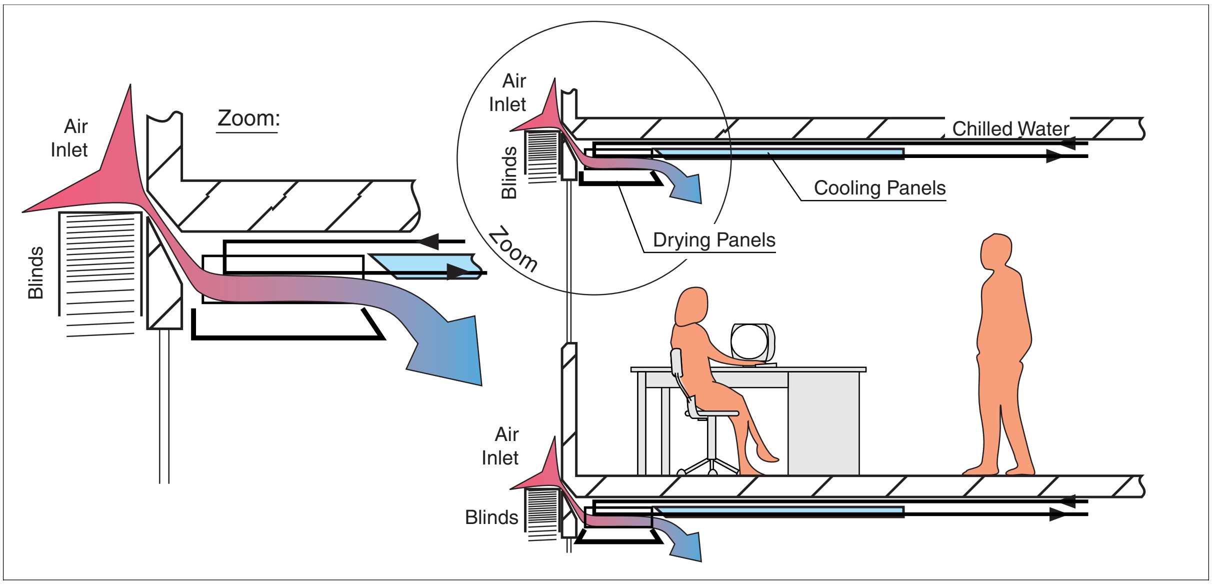

Figure 5 Integration of a condensing unit with an air inlet in the building façade

PARTIAL DECENTRALIZATION OF COLD PRODUCTION

Caused by the thermo-electrical modules, a fraction of the production of cold is performed in each room, in contrast to common installations, where a mechanical central unit provides the entire cooling. Centralized production is generally more energy and cost effective. But to make the condenser more compact, it is necessary to operate it at a lower temperature. This rises however the thermal loss and the risk of causing condensation along the piping system. A decentralization of the production of cold allows to increase the heat flux density at an equal inlet temperature. Furthermore, cooling ceilings are usually equipped with a warning sensor to indicate too high moisture contents of the air. The signal of such a sensor could also be used to switch the dehumidifier on and off. Local control would provide energy savings, because the dew point can vary significantly from one room to another (window openings, occupants, etc.).

CONCLUSION

A first prototype of a ceiling condenser has been built and tested. It has to be redesigned to improve the aesthetics, so that it is ready to target the market. A full integration into the ceiling is desired. Our research efforts show that the full set-up (panels and condensing units) allows a reduction of the installed power of the air-conditioning system. The reason is the advantage of having the possibility to control the temperature of the panels in the vicinity of the dew point. This leads to an improvement of comfort:

- Less draughts
- Less risks of dry eyes or/and dry throats.

Mounting the condensing units into the panels will increase the total performance (better heat sink). Then the system will be powerful enough to keep the air humidity in the room below 70 %. In numerous cases it will be even possible to replace the entire (convective) air-conditioning system. The following advantages are expected:

- No noise
- Perfect adaptation of system to building retrofits (no air ducts, only water piping system)
- Substantial energy savings (use of low exergy sources)
- Less restriction on window opening.

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