View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by Purdue E-Pubs

Purdue University
Purdue e-Pubs

International High Performance Buildings Conference

School of Mechanical Engineering

2010

Savings Potential with Thermo-Active Ceilings & Free Cooling

Mark Allen Murphy
SINTEF Building and Infrastructure

Follow this and additional works at: http://docs.lib.purdue.edu/ihpbc

Murphy, Mark Allen, "Savings Potential with Thermo-Active Ceilings & Free Cooling" (2010). *International High Performance Buildings Conference.* Paper 20.
http://docs.lib.purdue.edu/ihpbc/20

This document has been made available through Purdue e-Pubs, a service of the Purdue University Libraries. Please contact epubs@purdue.edu for additional information.
Complete proceedings may be acquired in print and on CD-ROM directly from the Ray W. Herrick Laboratories at https://engineering.purdue.edu/Herrick/Events/orderlit.html

Savings Potential with Thermo-active Ceilings & Free Cooling

Mark Allen MURPHY

SINTEF Building and Infrastructure
Trondheim, Norway
Mark.Murphy@sintef.no

ABSTRACT

The largest potential for decreasing green house gas emissions, and therewith mitigating the effects of global climate change, comes from improving energy efficiency. Through the integration of heating and cooling systems into building elements, such as the thermo-active ceiling, improvements in energy efficiency can be achieved.

Utilizing thermal mass to buffer temperature variations and to level out peak loads reduces the instantaneous power demands and enables traditional cooling equipment to operate in temperature ranges with higher coefficients of performance. Additional savings in both energy and money can be obtained through the use of free cooling, especially in northern climates. As the coolant temperature in a thermo-active ceiling approaches room temperature, the cooling potential of outdoor ambient air increases. This temperature difference enables free cooling at the mere cost of blowing outdoor air through a heat exchanger.

1. INTRODUCTION

As buildings become more and more energy efficient, the need for traditional radiator systems decreases. Draught caused by cold glass surface temperatures becomes a problem of the past, and heating systems can be optimized differently. Strategic positioning of the radiators will depend upon the building's ventilation system and how tempered air circulates within the building (Wigenstad, 2009). Meanwhile, spatial optimization will advocate integrating the heating and cooling systems into building components and freeing up floor space that was once occupied by the radiator system.

Floor heating and chilled ceilings are examples of integrated systems. When using the entire ceiling or the entire floor, they can evenly distribute heating and cooling throughout the building with temperatures closer to room temperature than traditional point source heating with radiators and cooling with cooled ceiling panels. This allows traditional cooling equipment to operate with higher efficiency and increases the potential for free cooling through the use of outdoor ambient air.

This paper focuses on the savings potential of thermo-active ceilings coupled together with free cooling through a dry fluid cooler. A thermo-active ceiling utilizes thermal mass activation to supply radiant heating and cooling to a room. This is achieved by embedding pipes into thermally massive materials, such as concrete. The exposed concrete is then allowed to interact with the room. To enhance this interaction, cooled or warmed water is pumped through the embedded pipes within the concrete. By adjusting the water temperature and flow rate, the cooling and/or heating power can be regulated. Meanwhile, the circulating water is tempered through the use of free cooling with a dry fluid cooler. A dry fluid cooler blows outdoor ambient air through a heat exchanger to cool down water or a glycol mixture that circulates through closed pipes, unlike a cooling tower that allows water to evaporate.

2. SIMULATIONS

When assuming traditional air supply and extraction, it can be assumed that the air within each room is well mixed. This assumption enables simulation with building energy simulation (BES) software. With BES software, one level of an office building was simulated. The rectangular building was 17.8 by 42.5 meters and orientated towards the south. The fenestration (window to wall ratio) was 40% on the eastern, southern, and western facades. It was 33% on the northern façade. The windows were passive house standard windows with a u-value of 0.8 W/m^2K. The outer walls had a u-value of 0.15 W/m^2K. Air leakage is normalized to 0.05 air circulations per hour (ach^{-1}), which represents a leakage rating of about 0.6 ach^{-1} at 50 Pascal pressure difference (BE, 2007).

The office building has operational hours from 8 am to 8 pm, Monday to Friday. During office hours, the ventilation rate is 5 air circulations per hour. Outside of office hours, the internal heat gain is zero and the ventilation rate is reduced down to 1 air circulation per hour. The supply ventilation temperature was constrained to 18 degrees during operational hours, but it was allowed to change for nighttime cooling and morning pre-heating. Nighttime cooling changed the supply ventilation temperature by adjusting the bypass valve within the air handling unit, which has a temperature efficiency of 80%. Without increasing the ventilation rate, nighttime cooling is free. Morning pre-heating, on the other hand, requires additional energy input.

Laboratory experiments of Weitzmann (2005) indicate that the cooling potential of the floor is significantly less than that of the ceiling. As cooling is the dominant heating mode within the office building that was investigated, the thermo-active element was integrated into the ceiling, as shown in figure 1. The floor was simulated as an adiabatic intermediate floor with the same temperature above and below.

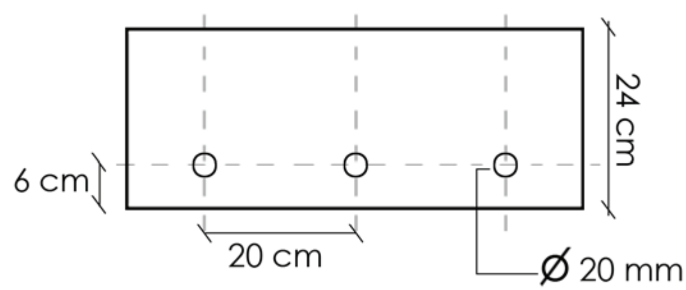

Figure 1 – Thermo-active ceiling cross section showing plastic pipes embedded 6 cm into concrete

The internal heat gains were set to 50 W/m^2 during office hours. This represents the upper limit for the thermo-active ceiling as determined by Weitzmann (2005) and verified by Murphy (2010).

2.1 Water Loop

Space heating and cooling is controlled through the thermo-active ceiling by regulating the temperature of the water entering the ceiling. The tempering of the circulating water is performed using first a dry fluid cooler and then secondly an auxiliary cooling device. The setpoint temperature of the dry fluid cooler is the desired inlet temperature of the thermo-active ceiling. An iterative loop controls the fan power while an On-Off switch confirms that the ambient temperature is at least one degree colder than the water flowing into the dry fluid cooler.

During the summer when the outdoor ambient temperature becomes too high or the dry fluid cooler does not succeed in cooling the water all the way down to the setpoint temperature, an auxiliary cooling device steps in to ensure that the water entering the thermo-active ceiling holds the desired inlet temperature. During the remainder of the year, the auxiliary cooling device is disabled and the dry fluid cooler covers the entire cooling demand on its own. Minor variations in the inlet temperature are absorbed by the thermal mass within the thermo-active ceiling.

The building was simulated using weather data from Trondheim, Norway. During 6 months of the year, the dry fluid cooler operated in summertime mode with auxiliary cooling to ensure adequate cooling of the thermo-active ceiling. During the remainder of the year, the dry fluid cooler operated in winter mode without additional cooling. The setpoint temperature of the cooling system was 19℃ all year round.

The fluid flow rate within the thermo-active ceiling was held constant at 320 kg/hr and the extra pumping energy required, in order to maintain this circulation, was roughly approximated to 2 kWh/m^2. The following figure shows the system diagram for the cooling system.

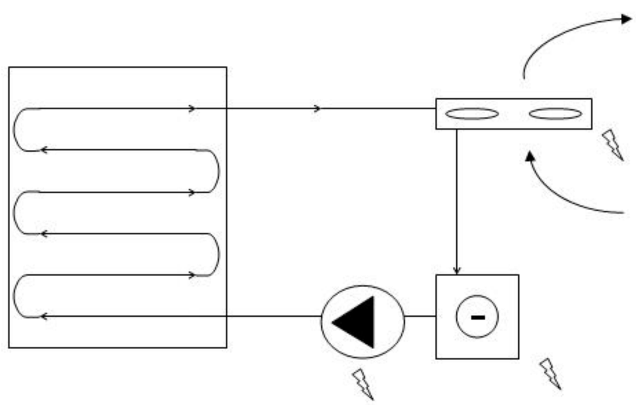

Figure 2: System diagram for the cooling system – the water loop

3. RESULTS

Two identical buildings were simulated with an internal heating gain of 50 W/m^2. One was equipped with thermo-active ceilings and free cooling while the other used heating and cooling to stay within the temperature interval 18-26 degrees centigrade. The annual energy use is broken into several posts and shown in table 1 below.

Table 1: Annual Energy Use [kWh/m^2]

Annual Energy Use [kWh/m^2]	Normal	Thermo-active + Free
Ventilation Heating Demand	8.0	8.6
Ventilation Cooling Demand	1.7	1.7
Space Heating Demand	0.8	-
Space Cooling Demand	61.0	-
Free Cooling Fan Energy Demand	-	0.7
Auxiliary Water Cooling Demand	-	4.6
Extra Pumping Energy	-	2.0

The cyan (dark gray) represents a thermal cooling demand and the light green (light gray) represents an electrical demand.

The 0.7 kWh/m^2 free cooling fan energy supplied 59 kWh/m^2 cooling to the circulating water. When combined with the auxiliary water cooling demand, the building would require in total more cooling than the traditional building. But thanks to free cooling with outdoor ambient air, the fan power needed to supply this amount of cooling is only a tiny fraction.

The savings potential of free cooling is made visible by converting the highlighted thermal cooling demands in table 1 into electrical demands. Using a heat pump, with various coefficients of performance, to convert the thermal cooling demands results in the following table:

Table 2: Savings potential for Thermo-active Ceilings with Free Cooling

System	**Component**	**Thermal Demand**		COP 3	COP 4	COP 5
Normal	Space Cooling Demand	61.0	⇒	20.3	15.3	12.2
Thermo-active ceiling with Free Cooling	Auxiliary Water Cooling Demand	4.6	⇒	1.5	1.2	0.9
	Free Cooling Electrical Demands			2.7	2.7	2.7
			Savings Potential [kWh/m^2]	**16.1**	**11.4**	**8.6**

The difference between the electrical demands of the two cooling systems is the savings potential for thermo-active ceilings with free cooling, which ranges between 8.6 and 16.1 kWh/m^2.

4. DISCUSSION & CONCLUSIONS

The thermo-active ceiling succeeds in cooling away internal heat gains up to 50 W/m^2. During the majority of the year, the office building has a cooling demand that can be met entirely by free cooling. Less than ten percent of the annual cooling demand must be obtained through auxiliary water cooling.

Using the thermal mass spread over the entire ceiling enables the inlet temperatures of the thermo-active ceiling to be closer to room temperature than traditional cooling systems. The typical temperature range of 12-14 degrees in chilled ceiling panels is unnecessary. Therefore, cooling equipment can be smaller, less complicated, and operate with less power as it is easier to cool temperatures closer to room temperature.

Initial investment costs for the thermo-active ceiling and free cooling combination may potentially be balanced out by the reduction in heating and ventilation equipment. Radiators and cooling panels are no longer needed and additional floor space usually utilized by these installations is made available. Meanwhile the operational costs, as shown in table 2, provide a savings potential between 8 and 16 kWh/m^2 when compared to a traditional system using a heat pump to supply cooling. The savings potential coupled together with the possibility of marginal investment cost could easily make such a system economically justifiable.

REFERENCES

BE, 2007, *Energi Temaveiledning TEK 2007*, Statens Bygningstekniske Etat, 54 p.

Murphy, M., 2010, *Thermo-active Ceilings & Free Cooling*, SINTEF Building and Infrastructure, 18 p.

Weitzmann, P., 2005, *Komfortforhold og lastudjævning ved energieffektiv køling med temoaktive konstruktioner*, COWI, 92 p.

Wigenstad, T., 2009, *Prosjektveileder: Forenklet anlegg for vannbåren oppvarming av boliger*, SINTEF Byggforsk, 36 p.