LOW ENERGY COOLING TECHNIQUES FOR RETROFITTED OFFICE BUILDINGS IN CENTRAL EUROPE

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ABSTRACT

Until the 1970's most office buildings in central Europe were not equipped with mechanical cooling (air-conditioning). Due to increasing requirements for thermal comfort and warmer summers, nowadays mechanical cooling is often applied to such buildings, however without caring for energy consumption and without considering possibilities of low energy or passive cooling.
This paper discusses options for incorporating low energy cooling technologies when retrofitting office buildings in central Europe. Climate analysis, design recommendations and role of computer simulation of building and system in the design process are presented. Applicability of night ventilation, evaporative cooling, and cooled ceiling panels, which can provide optimal thermal comfort in a conditioned space in relation to low energy consumption, will be analyzed. The slab cooling using existing slab heating system is stressed in the paper.

KEYWORDS

low energy cooling, slab cooling, computer simulation, retrofit, office building

INTRODUCTION

In Europe buildings account for approximately 40 to 50% of total primary energy consumption. In office buildings, about 10% of the total energy consumption is needed for comfort cooling. More and more offices are fully air-conditioned. In the Czech Republic, most new or reconstructed offices are equipped with full air-conditioning. The increasing use of computer and auxiliary equipment has led to an increasing demand for cooling in commercial buildings. The energy consumption for comfort cooling is significant . The associated impact on greenhouse gas emissions is enhanced by the fact that these cooling systems are usually electrically driven and electricity in the Czech Republic is mostly produced by coal power plants (Santamouris 1996, Heap 2001).
Based upon the Kyoto Protocol, European countries have agreed to agreed to decrease energy consumption in buildings and thus to cut down greenhouse gas emissions. One promising way to solve the discrepancy between increasing demand for thermal comfort and the necessity to reduce CO2 emissions is the application of low energy cooling techniques .

LOW ENERGY COOLING TECHNIQUES

Low energy cooling techniques aim to reduce energy consumption and peak electricity demand. They do so by making use of low exergy (ie. low quality) cooling sources such as the ambient air, the ground or surface water. These technologies are also referred to as passive or hybrid cooling systems. Passive cooling systems should not be confused with passive cooling building design, which mainly focuses on reducing the cooling load.

Low energy cooling techniques can be divided into two groups: those, which include a cooling source and those that focus solely on delivery of cooling to the treated space (IEA 1995, Liddament 2000).

The first group of systems rely on natural sources of cooling, but fans or pumps are required for most of them. The following technologies can be placed in this group:

- Night ventilation – lowers the temperature of the building thermal mass by night ventilation
- Evaporative cooling – sensible heat is absorbed as a latent heat to evaporate water
- Ground cooling – the air is cooled by the ground via matrix of piping or groundwater (aquifer) cooling

The second group of technologies focus on delivering the cooling to the treated space in an efficient manner, those technologies work usually well with lower grade sources of cooling. The following systems can be placed in this group:

- Slab cooling – thermal mass of slab is cooled by air or water
- Chilled ceilings and beams – ceiling panel or beam is cooled
- Displacement ventilation – conditioned air is emitted at low level at very low velocity

RETROFIT OF OFFICE BUILDINGS

Office buildings in the Czech Republic can be roughly categorized into three main groups according to construction style in relation to the time of building

A. Massive construction (brick, concrete), window area up to 30% of the façade, build up to the 1950-ies. Those buildings are usually not air-conditioned, or mechanically ventilated. Retrofit of such buildings is always individual. High thermal mass usually helps to maintain thermal comfort if passive cooling rules (low internal gains, shading) are obeyed during retrofit.
B. Buildings with a heavy concrete frame and floors and light prefabricated envelope, windows up to 60% of the facade. Neither air-conditioning nor mechanical ventilation was standard for this type of buildings. A very high percentage of current Czech stock of office buildings fall into this category. Retrofit of this type is an actual problem, and since there is no mechanical ventilation system and there is limited space to incorporate an all-air system, cooling possibilities are limited.
C. Modern office buildings with glass façade, lowered ceilings, carpets, usually fully air-conditioned.

This paper mainly addresses type B buildings and focuses on options for using existing water based ceiling heating systems for cooling purposes. The effects of natural ventilation and shading will be discussed as well.

Since traditionally type B buildings do not have mechanical ventilation, it would be very unpractical to apply any system requiring central air treatment such as systems based on evaporative cooling, ground cooling or forced night ventilation.

CEILING HEATING AND COOLING

Many of the B type buildings are heated by a ceiling (slab) heating system, commonly known as Critttal system. This system consists of a serpentine heating pipe embedded in the concrete massive ceiling. The system is based on the 1932 patent of the Dutchman J.K.C. van Dooren.

A radiant cooled ceiling is a relatively efficient cooling system, which is nowadays popular for new commercial buildings. Sensible room heat gains are dissipated by large-area water-cooled ceiling panels. Another type of radiant cooling system is slab cooling, in which the thermal mass of the floor/ceiling slab is cooled by water. For both system types, the supply airflow can be limited to the fresh air frequirements.

This paper is about using/converting the existing Crittal heating system for cooling in the summer.

Condensation risk is one of the main issues in radiant cooling systems. The inlet water temperature for the cooled ceiling has to be such that no surface condensation will occur (ie. the ceiling surface temperature has to be higher than the room air dew point temperature). For the light ceiling systems a fine control can be used to assure that the minimal surface temperature remains higher than the dew point temperature. It is not possible to use a fast control system for the ceiling slab embedded cooling system, because there is a large time delay (hours). Therefore the surface temperature must be kept higher than for the lightweight systems. In Czech offices with no additional moisture sources the maximum dew point temperature is about 16°C.

This is why for real systems the supply water temperature usually varies from 16 °C to 20 °C and the temperature difference between inlet and outlet cooling water is commonly $2 \leq \Delta T \leq 4$ K.

THERMAL COMFORT- OPERATIVE TEMPERATURE

The operative temperature t_o was chosen as the evaluation criterion for thermal comfort in air-conditioned spaces with radiant cooling or heating. The operative temperature depends on air temperature t_a; mean radiant temperature - *MRT* and air velocity w_a. From these quantities the thermal comfort in conditioned spaces can be predicted by means of the *PMV* (predicted mean vote) / *PPD* (predicted percentage dissatisfied) index according to ISO Standard 7730. The comfort range of thermal comfort is normally considered as $-0.5 < PMV < 0.5$ corresponding to $PPD < 10$ %.

The operative temperature t_o is defined as the uniform temperature of a radiantly black enclosure in which an occupant would exchange the same amount of heat by radiation plus convection as in the non-uniform environment. The following formula is used

$$t_o = At_a + (1 - A)MRT \qquad [\,°\mathrm{C}\,] \qquad (1)$$

where A is a function of the relative air velocity (from 0,5 to 1). When the air velocity is lower than 0.2 m/s, operative temperature approximately equals the globe temperature t_g and can be calculated as the average of air temperature and MRT.

The influence of the surface temperature on thermal comfort is significant; therefore if there is a cooled surface in the room it is possible to keep a higher indoor air temperature to achieve the same thermal comfort.

MODEL DESCRIPTION

Simulations were carried out for a typical office of 4.92 by 5.5 m with a room height of 3.2 m. There are two south-east facing windows resulting in 55% glazing of one of the walls. The model of the office is shown in Figure 1. As indicated, the office model consist of two thermal zones (with uniform air temperature) representing the “office zone” and the “cooled ceiling zone”.
Internal heat gains representing three occupants (3 x 62 W) each with PC (3 x 40 W) and monitor (3 x 58 W) are incorporated in the model. The heat gain schedule for a working day is shown in Figure 2. In the model no heat exchange through the internal wall is assumed since the surrounding rooms are assumed to have the same thermal conditions.

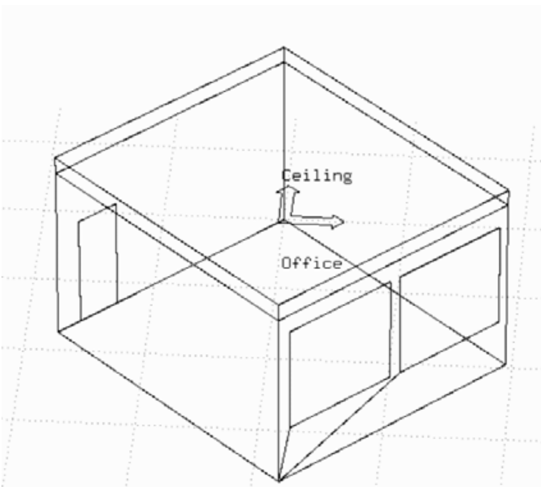

Figure 1: Office model in ESP-r software

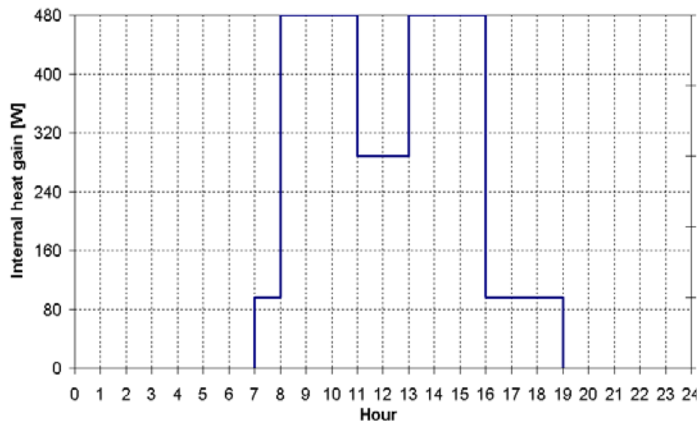

Figure 2: Schedule of the internal heat gain

SIMULATION AND RESULTS

Two passive cooling methods for improving thermal comfort in the not air- conditioned office in the summer were tested: decreasing the solar heat gains by shading or reflection and natural ventilation strategies.
The simulations were carried out for three ventilation strategies:
V1 only infiltration - air exchange rate 0,5 h^{-1}; for 24 hours a day
V2 night ventilation - air exchange rate 5 h^{-1}; from 18:00 to 7:00
V3 daytime ventilation - air exchange rate 10 h^{-1}, from 7:00 to 18:00 (if the outside temperature exceed 24 °C the ventilation was set back to basic infiltration 0,5 h^{-1})
Three types of glazing were simulated.
S1 Standard double glassing with solar factor 0,71
S2 Antisun bronze glassing with solar factor 0,48
S3 Glassing with internal blinds, solar factor 0,2
All cases have been simulated without slab cooling (C0) and with slab cooling (C1), the cooling layer temperature was set to 17 °C for 24 hours a day, 7 days a week. This makes 18 combinations.
The simulations were carried out for three summer months, using a weather test reference year (hourly data) for Prague.

Some of results for a selected period of two weeks are presented in Figure 3, Figure 4 and Figure 5. The 3 months results are summarized in the Table 1.

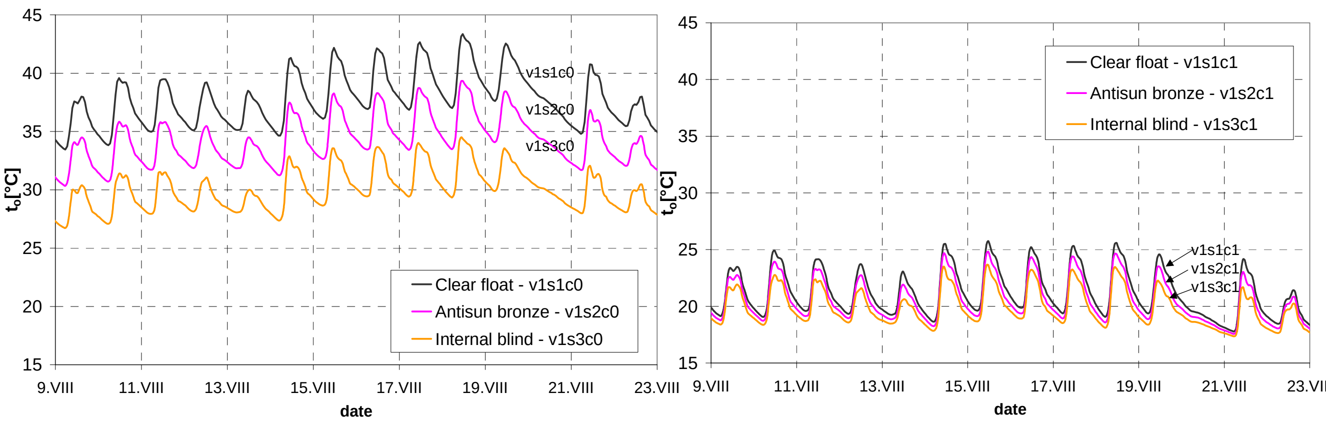

Figure 3: Operative temperature during two summer weeks assuming infiltration only, different glazing types, without (left) and with ceiling cooling.

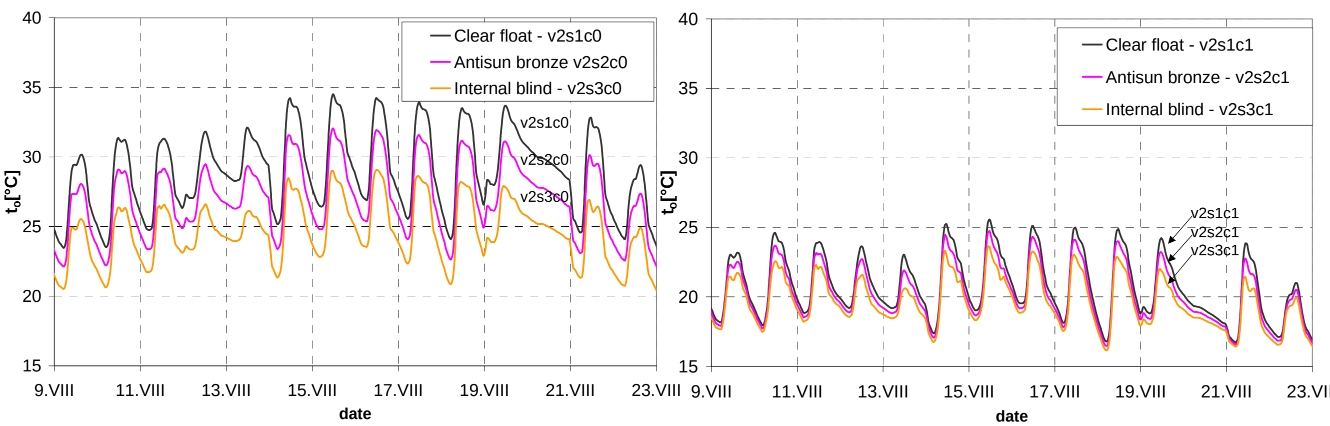

Figure 4: Operative temperature during two summer weeks assuming night ventilation, different glazing types, without (left) and with ceiling cooling.

Table 1: Number of working hours during three summer months with the operative temperature in a specific interval

Operative temperature	**from**		**18**	**24**	**28**	**32**		**18**	**24**	**28**	**32**
	to	**18**	**24**	**28**	**32**		**18**	**24**	**28**	**32**	
Ventilation	**Glassing**	**Without ceiling cooling**					**With ceiling cooling**				
Infiltration	Std.	0	0	0	143	583	23	648	55	0	0
Infiltration	Antisun	0	0	74	346	306	41	678	7	0	0
Infiltration	Blinds	0	48	370	271	37	71	655	0	0	0
Night vent.	Std.	0	104	367	218	37	54	647	25	0	0
Night vent.	Antisun	0	270	337	119	0	74	648	4	0	0
Night vent.	Blinds	5	487	218	16	0	115	611	0	0	0
Day vent.	Std.	133	415	172	6	0	192	522	12	0	0
Day vent.	Antisun	165	434	126	1	0	216	508	2	0	0
Day vent.	Blinds	227	464	35	0	0	256	470	0	0	0

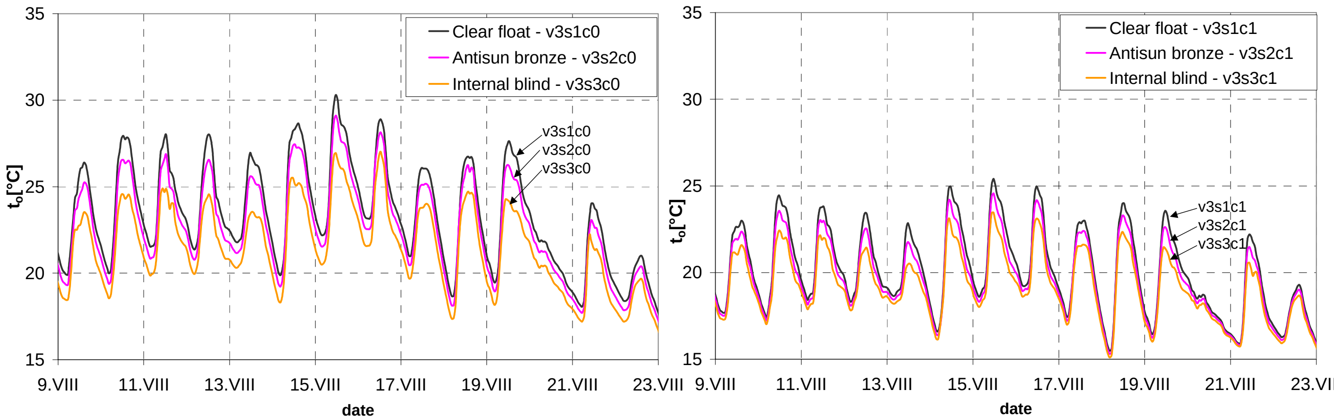

Figure 5: Operative temperature during two summer weeks assuming daytime mechanical ventilation, different glazing types, without (left) and with ceiling cooling

CONCLUSION

According to the simulation results all three low energy cooling strategies help to improve the indoor thermal comfort in the office. It is recommended to use antisun glassing with blinds especially if there is not other cooling technology. The operative temperature was decreased by 10 K if just infiltration was used (Figure 3. left) and by 5 K for night ventilation (Figure 4. left). The natural ventilation has even a bigger effect on the inside temperatures; this is due to the fact that in our simulation very high air exchange rates have been selected. In reality it is difficult to reach such values and there are other practical problems with such intensive natural ventilation (safety, draft etc.).

The ceiling cooling was approved as a system, which only one can fully guarantee thermal comfort in the office. The effect of ceiling cooling was much stronger that other considered technologies. The simulation results even show occasional overcooling of the office. The question of the optimal ceiling (cooling water) temperature and the control of the slab cooling system remain for future research.

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