COMBINATION OF LOW ENERGY AND MECHANICAL COOLING TECHNOLOGIES FOR BUILDINGS IN CENTRAL EUROPE

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SUMMARY
This paper discusses options for incorporating low energy cooling technologies combined with standard mechanical cooling in buildings in central Europe. Case studies, 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 will be analyzed.

INTRODUCTION
In Europe buildings account for approximately 40 to 50% of total primary energy consumption. More and more offices are fully air-conditioned in the Czech Republic. Increasing use of computer and auxiliary equipment has led to an increasing demand for cooling in commercial buildings. 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. Based upon the Kyoto Protocol, European countries have agreed to decrease energy consumption in buildings and thus cut down greenhouse gas emissions. One promising way to solve the discrepancy between the increasing demand for thermal comfort and the necessity to reduce CO₂ emissions is application of low energy cooling techniques. Low energy technologies are not often able to guarantee thermal comfort for the whole summer; therefore they can be combined with mechanical cooling.

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 (i.e. low quality) cooling sources such as ambient air and ground or surface water. These technologies are also referred to as passive or hybrid cooling systems. 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:
- Night ventilation – lowers the temperature of building thermal mass by night ventilation
- Evaporative cooling – sensible heat is absorbed as latent heat to evaporate water
- Ground cooling – air is cooled by the ground via matrix of piping or groundwater (aquifer) cooling

The second group of technologies focus on delivering 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

For some of the low energy technologies mechanical cooling (compressor cycle) can be used as a cooling liquid source (slab or ceiling cooling, displacement ventilation), some can
accommodate additional mechanical cooling as a part of the system (night ventilation, evaporative cooling) and some systems are combined with independent air-conditioning units.

**NIGHT VENTILATION**

The system is based on using low external air temperature during the night and high thermal mass of the building. For mechanical night ventilation it is necessary to optimize the flow rate during the night. Energy consumption of fans can be higher than consumption of mechanical cooling system if the flow rate is overestimated. Whole year computer simulation is one of basic methods to determine optimal night ventilation because of combination of building thermal mass and variable external temperatures and gains.

If a building with high thermal mass is equipped with a mechanical all air air-conditioning system a complex system called “top cooling” allows reducing energy consumption by night ventilation and by proper control of mechanical cooling as well.

**THE OFFICE BUILDING IN PRAGUE WITH TOP COOLING**

The first headquarters building in the Czech Republic to employ night-cooling for most of the office spaces was built in Prague (1998 – 2002). During the initial design process computer simulation was applied to prove the chosen conception. Second stage simulations based on a model calibrated according to the monitored data are carried out to optimize the air conditioning system control.

![Figure 1: Principle of the shading and night ventilating in the referred building.](image)

The thermal mass of the building was increased by using pure concrete ceilings with ribs (no false ceiling) and concrete floors without carpets in all open plan offices. The design of external shading elements eliminates solar gains from direct radiation on the south facade. A high performance heat recovery system in the central unit reduces the heat or cool consumption as well.

Building monitoring as well as second stage simulations proved a minimal need for mechanical cooling or heating in the building, especially during late spring or early autumn.

![Figure 2: Comparison of the building measurements and simulation results](image)
INFLUENCE OF STORED HEAT IN HEAVY CONSTRUCTIONS ON COOLING ENERGY DEMAND

One of the main disadvantages of traditional calculating and design methods for HVAC systems is underestimation of the impact of the heat capacity of the building. In the design of new galleries in the historical building of Sovovy Mlýny (watermills) in Prague, computer simulations were used to predict the required capacity of the cooling system. The initial design made by a standard calculation estimated the cooling capacity of about 100 kW. The cooling system was dimensioned accordingly. The simulation showed that for the indoor air temperature of 24°C the cooling capacity of 20 kW would be enough to remove both the external heat load and the internal heat gains from occupants and lights.

The study helped not only to lower investment costs for the cooling system but most of all to minimize changes in the construction of a valuable historical building. The simulation was combined with measurements in the existing building and indoor environment was assessed also for the case without any cooling device. The influence of the number of visitors, the lighting and open or closed shutters was tested.

EVAPORATIVE COOLING

Evaporative cooling is a process, which uses the effect of evaporation as natural heat sink. Sensible heat from the air is absorbed as latent heat necessary to evaporate water. The amount of sensible heat absorbed depends on the amount of water that can be evaporated. Evaporative cooling is a very old process, having its origins some thousand years ago in ancient Egypt and Persia. Evaporative cooling was one of the main cooling techniques before refrigerant vapor compression cycle. Evaporative cooling can be direct or indirect.

The determinative factor for evaporative cooling is outside air humidity. The evaporative cooling technology can be placed just in central all air air-conditioning system. Analysis of Czech climate shows stand alone direct or indirect evaporative cooling is not able to guarantee thermal comfort in office buildings. That is why direct evaporative cooling is usually combined with other cooling technologies in order to provide comfort thermal conditions for people throughout the whole year. The maximum capacity of chiller does not decrease significantly if such a hybrid system consists of a direct evaporative cooling device and a standard chiller. However, the number of operation hours decreases markedly, as you can see in the following example.
EVAPORATIVE COOLING OF THE INDONESIAN JUNGLE PAVILION

Modelling and simulation work was carried out to support the design team of the new "Indonesian Jungle" pavilion in Prague Zoo (Bartak 2001). This pavilion is basically a very large (a surface area of 1900 m² covering a volume of 14700 m³) transparent dome (see Figure 3) maintaining warm and humid (20 to 25 °C and 70 to 90 %) jungle-like indoor environment. Problematic issues include very high solar gains in summer, very high heat losses in winter, and potential condensation against the roof at various times throughout the year.

Figure 3: The ZOO pavilion construction and ESP-r software model

Direct evaporative cooling by spraying water in the pavilion interior was considered in order to cool the air adiabatically and thus reduce summertime cooling energy consumption and lower the maximum cooling loads. This was considered an interesting option since the Czech Republic has a relatively dry summer climate while the jungle pavilion requires high levels of relative humidity; i.e. in the range of 70% to 90%.

As can be seen in Figure 4 the simulation results indicate about 50 kW or 25% reduction in maximum cooling load due to evaporative cooling. The amount of time the cooling system is in use will be reduced from 2000 hrs to about 1000 hrs per year. The number of operating hours with high cooling loads, e.g. loads over 120 kW, will reach 80 hours per year only. In terms of cooling energy demand the differences are even bigger. Without direct evaporative cooling the cooling energy demand over a typical summer amounts to 89 MWh. With direct evaporative cooling and the maximum indoor relative humidity of 70% the demand is reduced to 41 MWh (54% reduction). With the maximum relative humidity of 90% the cooling energy demand reduces to 13 MWh (85% reduction).

CEILING SLAB COOLING

Slab cooling is a radiant cooled ceiling with high thermal mass. Sensible room heat gains are dissipated by large-area massive water-cooled ceiling panels. The cooling water temperature is usually close to 20°C. Therefore this system is suitable for high temperature (low potential) cooling sources. The maximal performance of cooled ceilings is approximately 50 W/m².
APPLICABILITY OF LOW ENERGY COOLING TECHNOLOGIES FOR RETROFIT OF MECH. ENG. FACULTY BUILDING

Computer simulations for a typical office room in the building were carried out. There are two south-east facing windows resulting in 55% glazing of one of the walls. Model of the office is shown in Figure 1. 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.

Two passive cooling methods (shading, natural ventilation) for improving thermal comfort in a not air-conditioned office in summer were tested. : decreasing solar heat gains by shading or reflection and natural ventilation strategies. All cases have been simulated without slab cooling and with slab cooling.

According to the simulation results all three low energy cooling strategies help to improve indoor thermal comfort in the office. It is recommended to use antisun glazing with blinds especially if there is not other cooling technology. Operative temperature was decreased by 10 K if just infiltration was used and by 5 K for night ventilation.

Ceiling cooling was approved as the only system, which 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 (Figure 6.). The question of the optimal ceiling (cooling water) temperature and the control of the slab cooling system remains for future research.

ROLE OF COMPUTER SIMULATIONS

As you can see from previous case studies the use of computer modelling and simulation for the design and/ or evaluation of buildings and HVAC is quickly moving from the research and development stage into everyday engineering practice. In contrast to the traditional simplified calculating methods (not considering the system dynamics), computer based modelling approaches reality much closer. Especially for low energy and hybrid system design the role of computer modelling and simulation is more important. Dynamic interactions of the building, climate and plant system play the crucial role for most low energy cooling technologies.

Computer simulations demand more input information and data processing than ordinary design work. On the other hand, once the model is prepared, simulation techniques allow
quick and detailed analysis of various solutions for the building geometry and construction as well as for the design and operation of HVAC systems. The aim of computer modelling is to optimize the design of a building and its service system according to the requirements for indoor air quality while keeping energy consumption at minimum levels.

All presented simulations were done with integrated building performance modelling and simulation environment ESP-r.

CONCLUSIONS

If thermal comfort for the whole summer is required in most office buildings low energy cooling technology has to be combined with mechanical cooling. Design and maintenance of such hybrid systems is usually very difficult but if it is done well energy savings can be considerable. Passive cooling reduces especially the operating costs (energy consumption) of hybrid systems, but in some cases the initial investments can be reduced as well. Computer simulation and modelling play the crucial role for the design and optimization of such hybrid systems.

REFERENCES