

Passive and low energy cooling techniques in buildings

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PASSIVE AND LOW ENERGY COOLING TECHNIQUES IN BUILDINGS

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ABSTRACT

The paper deals with applicability of passive and low energy cooling technologies in the Czech Republic. There are presented climate, buildings and systems analysis, to find out passive and low energy cooling technologies potential.

Some case studies including building simulations and monitoring are introduced (the office building with night ventilation, direct evaporative cooling, slab cooling, role of thermal mass in an historical building, thermal lops).

The role of computer simulation in the low energy building design and optimization is discussed.

INTRODUCTION

Buildings consume approximately 40 to 50% of primary energy in European countries. Energy consumption for cooling represents approximately 10 % of the total consumption for commercial office buildings. The percentage of fully air-conditioned office floor area is increasing in Europe, especially in the Czech Republic, where full air conditioning is the current de facto standard in new or reconstructed office buildings. The increasing use of information technology has led to an increasing demand for cooling in commercial buildings. Cooling thus accounts for a significant proportion of the total energy consumption in buildings, and its 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) .

LOW ENERGY AND PASSIVE COOLING TECHNOLOGIES

Low energy cooling technologies provide cooling in an energy efficient manner, thus reducing energy consumption and peak electricity demand. They do so by making use of low quality sources of cooling; whether it is ambient air or ground temperatures or warmer chilled water. Those technologies may be considered passive and hybrid cooling systems. (The term passive cooling should not be confused with passive cooling building design which is focused on reducing the cooling load).

Low energy cooling technologies can be divided into two groups: those including the main source of cooling 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. Examples of such technologies are:

- ☞ Night ventilation
- ☞ Evaporative cooling
- ☞ Ground cooling

The second group of technologies focus on delivering the cooling to the treated space in an efficient manner, those technologies usually work well with lower grade sources of cooling.

RESEARCH METHODS

Most low energy cooling technologies are strongly dependent on climate. Therefore a climate analysis was carried out to assess applicability and efficiency of these technologies. The analysis is based on a test reference year for Prague, which in itself was derived from 15 years of hourly data.

The second method which was used to find out the potential of various low energy cooling technologies, is a review of existing exemplary buildings. Because these are almost non-existing for the Czech Republic it was necessary to look at other regions with similar climate, buildings and systems.

The last but not the least method is building simulation. For passive and low energy cooling technologies, the dynamic behavior and interactions of building, systems, occupants and environment is very important. To design such systems and verify its performance the standard design methods based on peak gains are not suitable. In contrast to the traditional simplified calculating methods (not considering the system dynamics), computer based modeling approaches reality much closer. The use of computer modeling and simulation for the design and evaluation of buildings and HVAC is quickly moving from the research and development stage into everyday engineering practice. For most of the presented studies the ESP-r simulation software was used; in some cases combined with other software.

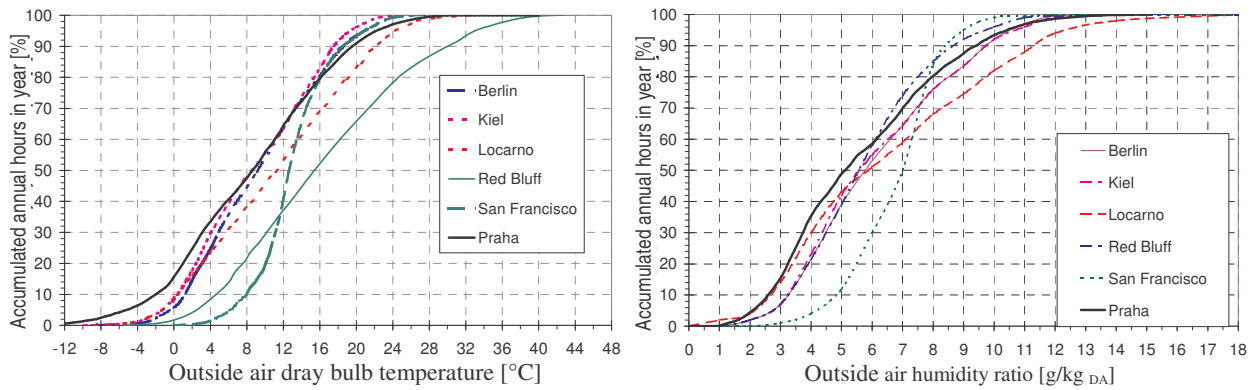


Figure 1: Cumulative distributions of the dry-bulb temperature (left) and humidity ratio (right) comparing Prague to five other climates (Bene 1997).

CLIMATE IN THE CZECH REPUBLIC

The Czech Republic is an inland country located in the middle of Europe. The capital and also the biggest city is Prague. Most governmental and business offices are located there. The Czech climate can be described as warm (summer peak design temperature 32°C) and semi-humid (summer design moisture content 10 g/kg and wet bulb depression 9 K).

When comparing the Prague climate to other cities, where some low-energy cooling studies have been carried out, it was found that the summer climate is very similar to Berlin (Figure 1). Therefore the Berlin summer results and experiences can be used for preliminary studies for Prague.

For evaporative systems enthalpy hours are defined which take into account the humidity of the air (IEA 1995). The cooling degree hours (CDH) and enthalpy hours (EH) were calculated twice, using two different reference temperatures, namely 18°C (index 18) and 25°C (index 25). The reference relative humidity for calculating enthalpy hours was 40%. Enthalpy hours and cooling degree hours for Prague are compared to some other towns in Table 1.

Table 1: Cooling degree hours and enthalpy hours

Town	CDH ₂₅	EH _{25/40} (kJ/kg _{DA})	CDH ₁₈	EH _{18/40} (kJ/kg _{DA})
Prague	361	3 047	4 581	25 198
Dresden	527	3 040	5 154	28 068
Stockholm	150	1 350	1 000	16 425
Zurich	426	1 658	4 757	16 380
New York	2 570	25 698	15 942	68 783
Toronto	837	12 294	7 643	40 831

RETROFIT OF EXISTING BUILDINGS

In view of the main subject of this paper, it is convenient to distinguish different building categories as follows.

HISTORICAL BUILDINGS

These are characterized by massive construction (brick, concrete), a window area up to 30% of the facade, and were build up to the 1950-ies.

These buildings are usually not air-conditioned, nor mechanically ventilated. Retrofit of such buildings is always individual. Most heavy historical buildings can be operated without air-conditioning. High thermal mass helps to maintain thermal comfort as long as passive cooling rules (low internal gains, shading) are obeyed during retrofit. The thermal mass of the building can guarantee comfort requirements.

Retrofitting the historical Prague Sovovy Mlýny (watermills) into an art gallery is a typical example with respect to the role of building thermal mass in a historical building. Initially the maximum cooling load was estimated at about 100 kW using standard calculations. The cooling system was dimensioned

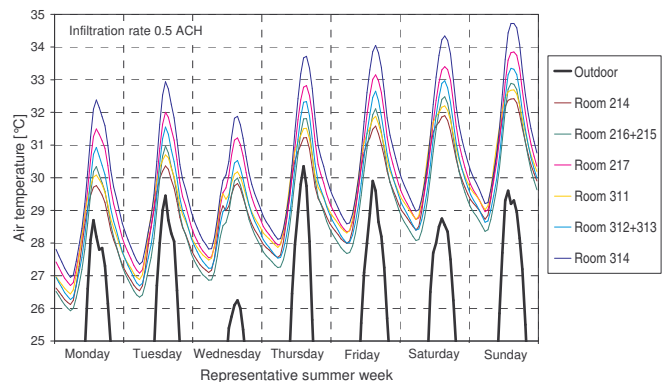


Figure 2: Watermills - temperature of indoor and outdoor air (ventilation without air-conditioning)

accordingly. Subsequent dynamic modeling and simulation, showed however that a cooling capacity of about 20 kW would be sufficient 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 (Barták 2001).

1950-1980 OFFICE BUILDINGS

These were build during the socialistic period and typically have 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. A very high percentage of current Czech stock of office buildings falls into this category. Retrofit of this type is an actual problem. This is the subject of an extensive study using computer simulation (Lain 2004). Applicability of night ventilation and cooled ceiling panels was assessed in the study. The simulations were carried out for a typical office with southeast facing windows for three ventilation strategies: infiltration only; night ventilation with air exchange rate 5 h^{-1} and daytime ventilation with air exchange rate 10 h^{-1} . Three types of glazing were considered: standard double glazing ($g = 0,71$); Antisun bronze glazing ($g = 0,48$) and standard double glazing with internal blinds ($g = 0,2$). All cases have been simulated with and without ceiling slab cooling.

Table 2: Number of working hours during three summer months with the operative temp. in a specific interval

Operative temperature	from	18	24	28	32
	to	18	24	28	32
Ventilation	Glazing	Without ceiling cooling			
Infiltration	Std.	0	0	0	143 583
Infiltration	Antisun	0	0	74	346 306
Infiltration	Blinds	0	48	370	271 37
Night vent.	Std.	0	104	367	218 37
Night vent.	Antisun	0	270	337	119 0
Night vent.	Blinds	5	487	218	16 0
Day vent.	Std.	133	415	172	6 0
Day vent.	Antisun	165	434	126	1 0
Day vent.	Blinds	227	464	35	0 0

From the results presented in Table 2 it can be seen, that these office buildings can be operated without air conditioning if good quality glazing and/ or shading is provided. Proper natural night or daytime ventilation can guarantee thermal comfort during almost the whole summer. If slab cooling would be applied, thermal comfort can be achieved during the whole summer.

RESIDENTIAL BUILDINGS

In the Czech Republic almost all residential buildings are operated without air-conditioning or cooling. The reasons are the relatively small window area (usually not more then 30% of facade), the high effective thermal mass (no suspended ceilings) and the relatively low internal gains. However for some houses, especially modern ones with a lot glazing, shading or advanced glazing is highly recommended.

NIGHT VENTILATION

There is a high potential for night ventilation in the Czech Republic. As can be seen in Figure 2, the difference between maximum day temperature and minimum night temperature is usually more then 10 K. (The mean daily temperature range is 11.6 K). Also, the minimum night air temperatures are well

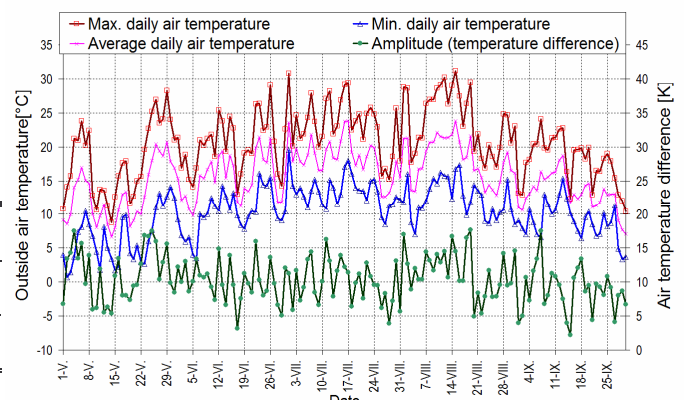


Figure 3: Air temperature difference variation in Prague during the cooling season.

below 18°C .

Not only night ventilation but also daytime ventilation can be used for cooling purposes in the Czech Republic. During 93% of the cooling season the outside air temperature is below 24°C . For working hours this is 94 percent.

The most common air-conditioning system nowadays consists of fan coil units in combination with a minimum of centrally treated fresh air supply ($50 \text{ m}^3/\text{h}$ per person which equals about 2 ACH). Even this small amount of external air can be used to reduce the cooling loads and energy consumption by

night ventilation as can be seen in the following example.

NEW BANK HEAD OFFICE

For a new large bank head office in Prague, computer simulations were carried out to find solutions for reducing the required cooling capacity. Because the design included exposed concrete ceilings, the idea was to apply building thermal mass

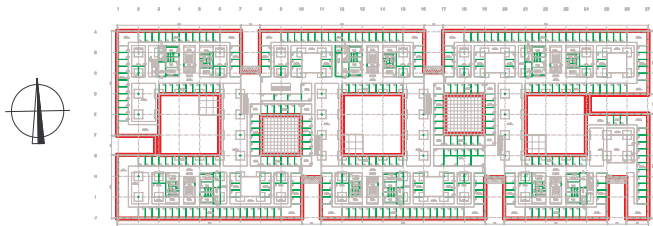


Figure 4: Ground plan of the office building

and find out a way how to operate the building.

For the 13 000 m² building with 4 floors the cooling capacity was initially estimated at 3 MW. The simulations proved that if the air temperature set point would be 24°C and the cooling capacity would be limited to 81 %, the inside air temperature will not exceed 26°C. If mechanical night ventilation would be applied, the cooling energy consumption decreases by 24% (from 1.6 GWh to 1.2 GWh).

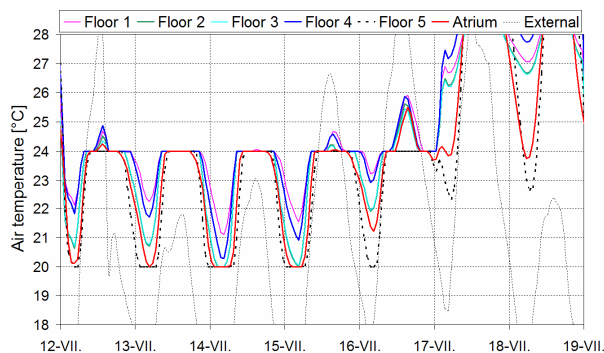


Figure 5: Inside air temperature in the bank office during a peak summer week

EVAPORATIVE COOLING

Applicability of direct evaporative cooling in office or residential buildings is limited due to thermal comfort considerations. If the maximum internal air temperature is 26 °C and humidity is 60%, the enthalpy of the external air should not exceed 52 kJ/kg. Analyzing the climate data it was found that there are 180 working hours when the outside enthalpy exceeds 52 and 82 hours when 26°C is exceeded as well. This is a considerable part of the cooling season. That is why direct evaporative

cooling is usually combined with another cooling technology, in order to provide comfort throughout the whole year. The maximum capacity of the chiller would not decrease significantly, if such a hybrid system consists of a direct evaporative cooling device and standard chiller. However, the number of operation hours and energy consumption decreases markedly (Lain 2003).

For spaces with higher required humidity (some industrial and agricultural applications) evaporative cooling is more suitable as became clear from a study for a new Indonesian jungle pavilion in the Prague Zoo. Water sprayed into the pavilion interior decreased the maximum cooling load from 215 kW to 160 kW. The time when the cooling system would be in use, was reduced from 2000 hrs to about 1000 hours per year (Barták 2001).

For indirect evaporative cooling the situation is similar, for the few hours in the year, the outside air

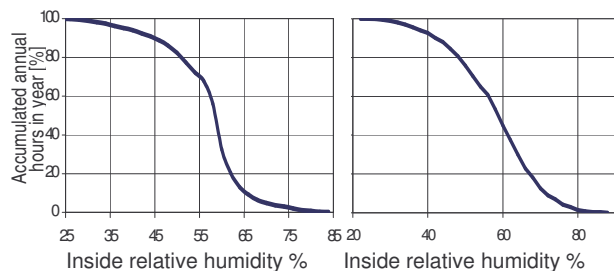


Figure 6: Cumulative distribution of indoor relative humidity for all air system (right) and indirect evaporative cooling (left)

enthalpy is so high that the system would not work.

Although the Czech climate is semi-humid, dehumidification is not needed for non-industrial buildings. Most air-conditioning systems incorporate some dehumidification by means of cooling coil condensation. If there is no condensation (or dehumidification) anywhere in the system the inside humidity exceeds the recommended maximum as can be seen in Figure 6 (Lain 2003).

GROUND COOLING

The Czech Republic has quite a rugged topography on a relatively small area. There are regions with very high underground water levels and artificial lakes (south Bohemia) as well as dry plains, mountains and river valleys. The soil differs very much from place to place and it is necessary to do geological prospecting to find local ground properties for underground systems.

The main barrier to wide use of ground water is not just its potential, but also the legislation. Each thermal use of underground water has to be approved

by the Ministry of the Environment. If there is a temperature difference between extracted and return water a charge per liter will be imposed.

Small air ground cooling systems are currently popular for low energy family houses with central air system in order to decrease summer peak temperatures. There is only one larger building in the Czech Republic which used ground cooling by means of buried pipes.

SLUNAKOV ECOLOGICAL CENTER

The Slunakov Ecological Education Center (SEV) has been designed for the city of Olomouc as part of a project entitled “Slunakov, facilities for ecological activities – educational bio-center in Horka nad Moravou”. The facilities are to be used to educate the public about the environment and its processes and to support public environmental awareness. The SEV building will also be used as the entrance to the protected nature area Litovelske Pomoravi (Hofmeister 2004).

The building has been designed as an inhabitable mound – a dune that fluently blends into the surrounding terrain. The earth-sheltered northern side of the building fluently adjoins the building’s earth-covered roof, which gradually increases in height from the west to the east, so that half of the building is one storey and the other half has two stories. The earth-covered roof is an important part of the urban concept.

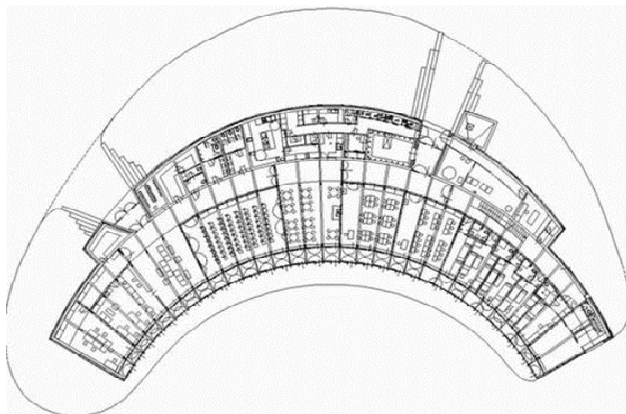


Figure 7 Ground plan of the Slunakov building

The building-energy concept was designed with respect to the basic principles of sustainable development. The building is designed for whole year operation with only a four-month heating season. The heating demand is covered by a combination of renewable energy sources – biomass and solar energy. The space heating demand is 81 MWh/year, corresponding to a specific heating demand of 14 kWh/(m³ year). The maximum specific

heating demand according to the current Czech legislation is 36 kWh/(m³.year). The amount of fresh air to be brought into the area is 3750 m³/hour (estimated for full occupancy, resulting in an air exchange rate of 0.77 h⁻¹).

The scale of the earth heat exchanger proposed for the Slunakov Center is unique in the Czech Republic. The system not only provides cool filtered air in the summer, but also preheats the fresh air in the winter. Earth heat exchangers are located in the earthen bank behind the building. Because of the limited space, several pipes are horizontally placed one above the other. The proposed solution can be classified as a compromise between the highest energy efficiency, pressure losses and the available investment capital. The control of the outdoor air is proposed as follows: if the external air temperature is above 22°C it is a cooling period, if it is below 12°C it is a heating period. During these periods the intake of external air goes through the earth heat exchanger. When the outdoor temperature is between 12°C and 22°C, the intake of fresh air goes directly from the vents located on the sidewalls of the building.

CONCLUSIONS

The benefits of using low energy and passive technologies are potentially very high in the Czech republic. Although there exist no major technical barriers, these technologies are not rapidly introduced due to economic reasons.

Only for a few recent offices a passive cooling concept was considered during the design. There exists no large new office building which was designed to use only passive cooling. Designing office buildings with more effective thermal mass and good quality shading in order to lower cooling loads is nowadays considered as good practice.

The design and commissioning of low energy systems is usually more complex than using standard air-conditioning. It requires better cooperation of all participants in the building design, construction and maintenance. Bad experiences with some systems are mostly due to lack of information exchange.

Advanced design methods (such as computer simulations) are already established in the Czech Republic, but the design fees (specially for HVAC system design) are usually not adequate for such complex methods. Sometimes during the construction a system is simplified in such a way that it is not able anymore to properly work. The systems are often operated without any knowledge about its principles.

Most large buildings in the Czech Republic are constructed by developers who are primarily

interested in decreasing investment costs and who do not particularly care about operational costs (energy consumption). It is up to building owners/users and legislation to drive the concern about building and system performance.

The Czech Republic's legislation only considered heating energy up to now. However after implementing European standards the regulations will have to include cooling (air-conditioning) as well. Because there is not much experience in cooling energy management, it will need some time to establish useful system of laws and regulations.

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