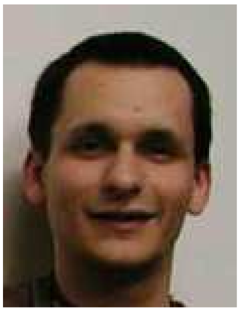
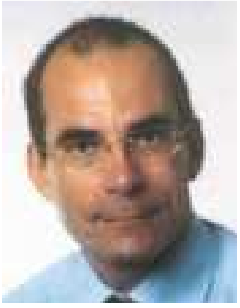
SLAB COOLING SYSTEM DESIGN USING COMPUTER SIMULATION



Milos Lain **Vladimír Zmrhal** **Frantisek Drkal** **Jan Hensen**

Summary

For a new technical library building in Prague computer simulations were carried out to help design of slab cooling system and optimize capacity of chillers. In the paper is presented concept of new technical library HVAC system, the model of the building, results of the energy simulations for summer operation, and application of the results do improved design and operation strategy. The slab cooling system consist of high thermal mass exposed concrete ceiling, in the ceiling slab there is in-build water pipe cooling system. To decrease chiller capacity the ceiling slab is cooled during night hours and during day there is no cooling source needed for library halls. In office part of the building there was no mechanical cooling applied at all, and inside operative temperature is find out using the model.

Keywords: Library, slab cooling, computer simulation. HVAC

1 Introduction

Many buildings are still constructed or remodelled without consideration of energy conserving strategies or other sustainability aspects. To provide substantial improvements in energy consumption and comfort levels, there is a need to treat buildings as complete optimized entities not as the sum of a number of separately optimized components. Simulation is ideal for this because it is not restricted to the building structure itself but can include the indoor environment, while simultaneously taking into account the outdoor environment, mechanical, electrical or structural systems, and traditional and renewable energy supply systems. By assessing equipment and system integration ideas, it can aid building analysis and design in order to achieve a good indoor environment in a sustainable manner, and in that sense to care for people now and in the future. Many heating, ventilation and air-conditioning (HVAC) design practitioners are already aware of building simulation technologies and its benefits in terms of environmental performance assessment of building designs. However, as yet, few (Czech) practitioners have expertise in using these technologies.

2 Technical library concept

2.1 Building concept

Technical library is a multi-storey object (6 floors and 3 undergrounds), which will be built in Prague 6 Dejvice. The building is divided to the several functional units. The main part of the building, the public library, is located in over ground floors (2^{nd}-5^{th} floor). The roofed atrium is integrated in the middle of the building (1^{st}-5^{th} floor) and also two little opened roof lights are placed in 5^{th} floor. There is parking in the underground floors. The building consists of steel concrete frame; internal walls are made from gypsum partition or glassed wall. Double envelope façade is used. External envelope consists of glazed components “Profilit“. Internal facade is light with high ratio of glazing.

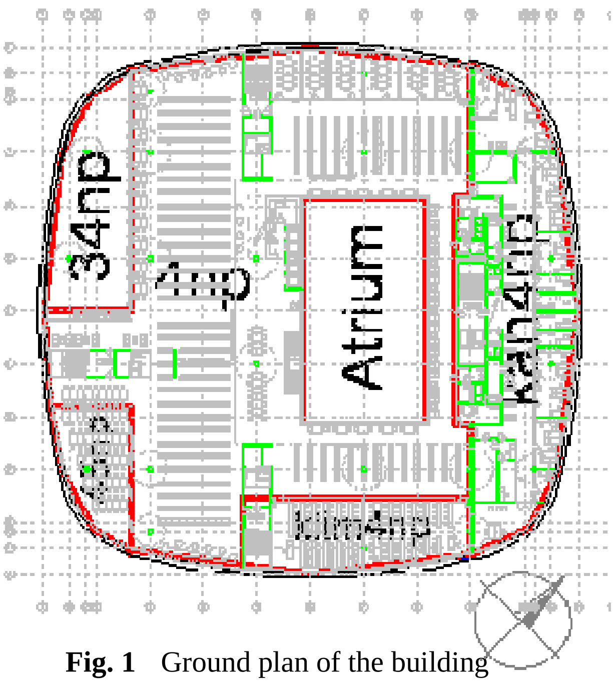


Fig. 1 Ground plan of the building with orientation (3rd floor)

2.2 HVAC system concept

The slab cooling is introduced to ensure thermal comfort in the main library hall and study rooms. This system consists of a serpentine heating/cooling pipe embedded in the concrete massive ceiling. The thermal mass of the ceiling slab is therefore cooled by water.

The supply airflow can be therefore limited to the fresh air requirements. The fresh conditioned outdoor air is distributed in the building. All air is exhaust via the atrium to the exhaust openings under the roof. Natural ventilation by windows is supposed in the offices (north-east façade) in 2^{nd}-5^{th} floor. The air change in offices is 2 h^{-1} during the day and 5 h^{-1} in the night is expected.

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). 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.

For computer rooms, and the restaurants and shops there is a common fan-coil system applied, because of the needed cooling capacity. The idea is that the cooling source (chiller) will be operated during peak gains (daytime) for fan-coil systems and during of-peak period (night) for slab cooling system. This lead to significant decreasing of needed chillier capacity.

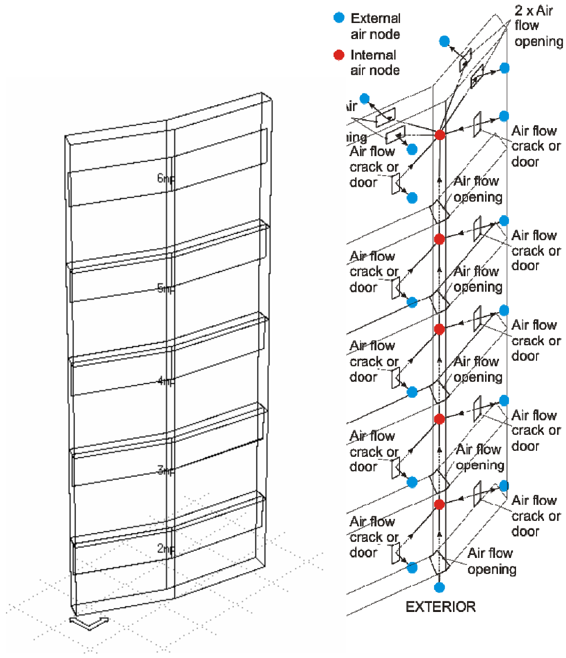
3 Methods –computer simulation

The use of computer modeling 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 modeling approaches reality much closer. Therefore it can be used especially for problems where the building and HVAC system is interaction is more complex.

Computer simulations are demanding 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.

The environmental system performance program (ESP-r) representing dynamic simulation environment for energy and mass transfer analyses in buildings, ventilation, heating and air-conditioning systems was used for the energy simulations.

Reference year of weather data for Prague was used for numerical simulations. The reference year does not represent typical weather data only; it considers dynamic changes as well as extreme values during a year. Numerical simulations were conducted in period from May 1st to September 30th.



4 Ventilated double facade

The selected South part of the ventilated double skin façade was modeled, to verify the proper ventilation. Model was vertically divided to 6 zones the outside facade is single glass, and the inside one double glass, there is internal shading element in each zone (floor). The flow network (**Fig. 2**) representing natural stack effect and wind driven flow was introduced to the model.

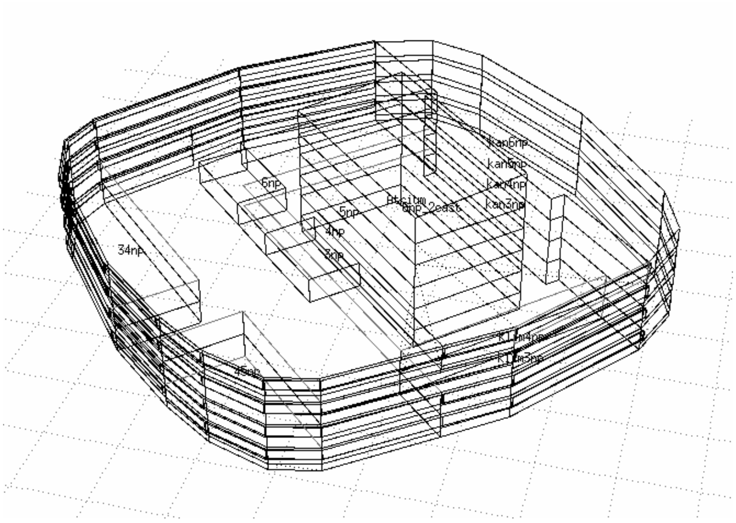


Fig. 2 Model of the technical library in ESP-r software

5 Library

5.1 Building model

The model of the building was created according to the investor requirements. Computer model solves the energy balance of the public library area (2^{nd}-5^{th} floor) with focus on extreme summer conditions. The verification of the system cooling performance was the main goal of the energy simulation

In a view of the fact, that the main accent was put on total energy balance in library space, the model was build up as whole building divided into 13 zones: public library (2^{nd}-5^{th} floor), atrium (1^{st}-5^{th} floor), office spaces (2^{nd}-5^{th} floor), 2 reading rooms and 2 computer rooms. Two small roof lights in 5^{th} floor opened are a part of the model. The model was simplified, because of technical possibilities of using software. The geometry of the floors correspond with the real building shape, only curved facades had to be replaced with straight segments (**Fig. 3**).

Air flow model

Building airflow model is visible in **Fig. 4**. Mechanical ventilation with constant airflow is supposed in the library. The temperature of the supply air is maximally 22 °C. If the outdoor temperature is less than 22 °C, the unconditioned outdoor air is supplied into the space. Also the ventilation of the offices is supposed in the model.

The air changes in the offices are defined as:

- 5 h^{-1} when the outdoor temperature is in range 20-24 °C
- 3 h^{-1} when the outdoor temperature is in range 24-26 °C
- 1,5 h^{-1} when the outdoor temperature is less than 20 °C
- 0,7 h^{-1} when the outdoor temperature is higher than 26 °C

Heat loads of the zones

The internal heat gain schedule for a working day was entered for thermal environment analysis. The values of internal heat gains are approximately 13.4 W/m^2 in library and 70 W/m^2 in computer rooms. Heat gains operation is supposed during the library open time from 7 am till 9 pm.

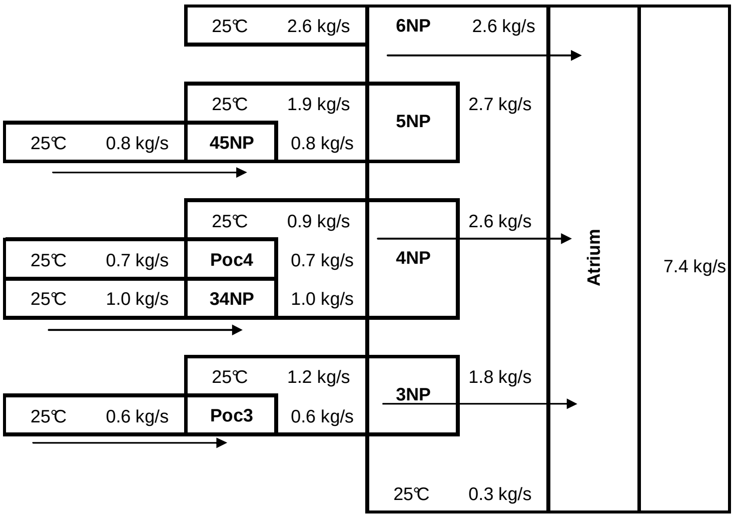


Fig. 3 Diagram of building airflow

5.2 Slab cooling model

The cooled ceiling with thermal storage into the building structure (concrete activation) – slab cooling will be used in the library and reading rooms. The cooling capacity of 40 W/m^2 is supplied into the concrete slab (at a depth of 150 mm) during the night (from 8 pm till 8 am). The temperature of cooling water is 18/21 °C; the spacing of pipe is 150 mm. The slab cooling area is less that total ceiling area. The slab cooling covers approximately 71 % of the ceiling. In the view of the simulation results, the concrete activation was completed with one hour during the day (1.30 pm-2.30 pm).

The air temperature in computer rooms is set up to 26 °C (air-conditioned rooms) during the open time of the library from 7 am till 9 pm). No cooling in offices was reflected. The computer energy simulation determines the necessary sensible cooling performance to air temperature observance (26 °C).

5.3 Verification of the model

The corrections of specification conditions were carried out in a few steps, especially the internal heat gains in library. Also the correction of used convection heat transfer coefficient (CHTC) was made. The higher CHTC compared with free convection along uncooled surfaces is used for cooled ceiling very often. The verification was carried by the CHTC sensitivity analysis. The analysis demonstrates that the indoor air temperature does not change markedly for different CHTC along the ceiling.

5.4 Results

The simulations were focused on summer only, with simulation period from May till September. Only cooling operation was reflected, therefore decreasing of air temperature can get in May or in September (no heating regime during the simulation is supposed). Results of the simulation (**Fig. 5**, **6**) are expected internal air temperatures, and cooling energy requirements. To find the optimal operation of the HVAC system there was 10 variants of slab cooling and ventilation operation simulated presented is just the final one.

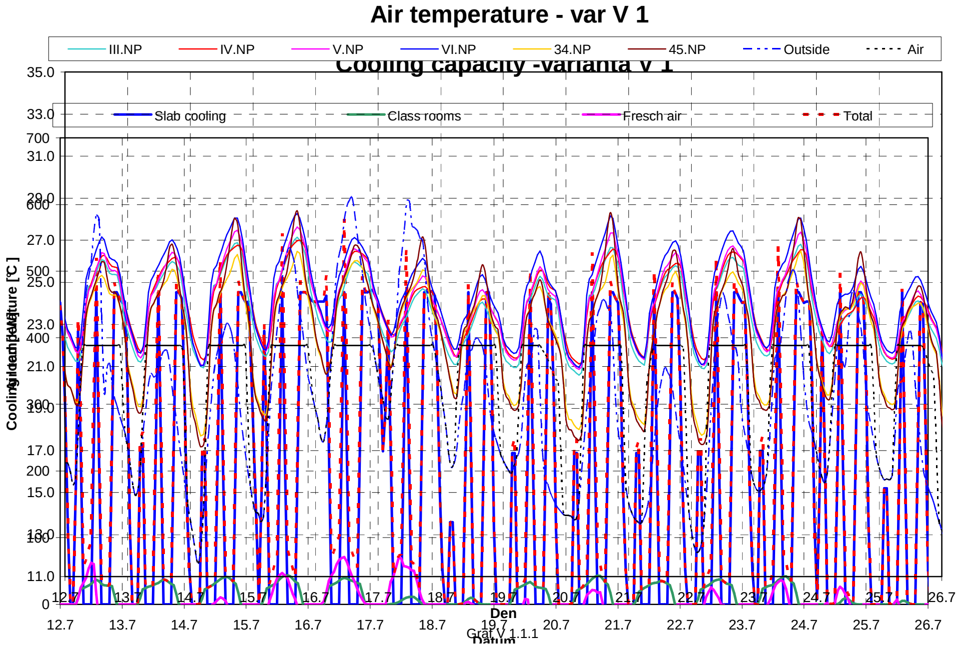


Fig. 5 Cooling capacity for library rooms and selected period

6 Conclusions

The double facade results approved, the temperature in ventilated double facade is closed to outside temperature. To keep onside air temperature below 27 °C it is necessary to cool the slab by the chilled water not only during the night, but also at least one hour during the day, if the library is fully operated in the summer peak. The computer simulation approved the HVAC system concept and helped to find out the operation strategy for the building.

References

[1] NAKAHARA, N. YOSHIDA, H. UDAGAWA, M. HENSEN, J. 1999. *Proceedings of the 6th International IBPSA Conference Building Simulation'99*. Volume I,II,III, Kyoto

[2] ESP-r 1998. *A Building Energy Simulation Environment. ESRU Manual*. Energy Systems Research Unit. University of Strathclyde, Glasgow

[3] ASHRAE Handbook 2001 Fundamentals, ASHRAE, Atlanta, 2001.

[4] ISO Standard 7730, Moderate thermal environments – Determination of the PMV and PPD indices and specification of the conditions for thermal comfort.

[5] LOVEDAY, D. L., PARSONS, K. C., TAKI, A. H., HODDER, S. G., JEAL, L. D. *Displacement ventilation environments with chilled ceilings: thermal comfort design within the context of the BS EN ISO7730 versus adaptive debate*. Energy and Buildings 34, 2002, p. 573 – 579.
[6] IEA, 1995, Review of Low Energy Cooling Technologies, Natural resources Canada, Ottawa, Canada, 88 p.

Ing. Miloš Lain
Prof. Ing. František Drkal, CSc.
Ing. Vladimír Zmrhal, Ph.D.
✉ CTU in Prague, Mech. Eng. Faculty
Technická 4
166 07 Prague 6, Czech Republic
☎ +420 22435 2586
🗐 +420 22435 5606
☺ milos.lain@fs.cvut.cz

Prof. dr. ir. Jan Hensen
✉ Technische Universiteit Eindhoven
Building Physics & Systems
P.O. Box 513 – Vertigo 6.18
5600 MB Eindhoven
TheNetherlands
☎ +31 (0)40 247 2988
🗐 +31 (0)40 243 8595
☺ j.hensen@tue.nl