Design and commissioning of the low-energy office building in Prague

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ABSTRACT

This paper deals with the use of computer simulations both for design support of a new building including its heating, ventilation and air-conditioning (HVAC) systems and for optimization of the HVAC control strategy during operation of the completed building.

In the early design phases for a new commercial building in Prague computer simulations were carried out in view of possible effects of night cooling ventilation. Predictions of the indoor environment and energy consumption for various options regarding cooling capacity and different outdoor ventilation rates supported the HVAC system design which included daytime top cooling and night ventilation with outdoor air combined with accumulation of cold in building constructions.

After completion of the building, occupants' complaints and a set of measurements indicated some problems with the HVAC, which were subsequently solved. Long-term monitoring and further computer simulations were performed in order to optimize the control strategy of the top cooling system.

1. BUILDING CONCEPT

The new headquarters for the ČEZ power company (one of the top ten largest European energy utilities and the strongest business entity on the Czech electricity market) in Prague is the first headquarters building in the Czech Republic to employ night-cooling and top cooling for most of its office spaces. Occupied by ČEZ since April 2002, it won the “Czech building of the year 2002” award by the Czech ABF foundation (Dvorak, 2002).

The building is divided into tree parts. It has two wings (six floors above ground, 600m2 each) with open-plan offices and an all-air system with top cooling and night ventilation. The central part houses the reception on the ground floor and individually air-conditioned offices on the higher floors. For night cooling, the thermal mass of the building is very important. The building features exposed concrete ceilings with ribs and concrete floors without any carpets. More than 50% of the façade is transparent. All south facing windows are fully shaded throughout the summer by external facade elements (Fig. 1).

The all-air centralized system for the two wings is controlled according to the return air temperature. It is a top cooling system meaning that the capacity is less than it would be according to the current cooling load standard. The cooling capacity is based on simulations in the early design phase. There is no individual control in the rooms nor on the floors. The system is operated 24 hours per day with a constant set-point of 24 °C. The temperature is allowed to drift up to 2 K during normal conditions and up

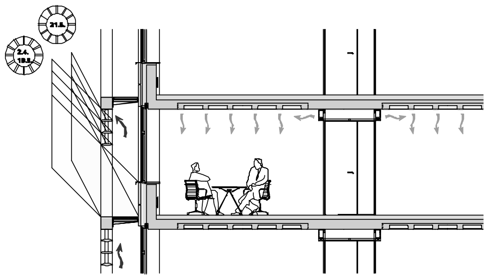

Figure 1: Principle of the shading and of the nighttime forced ventilation.

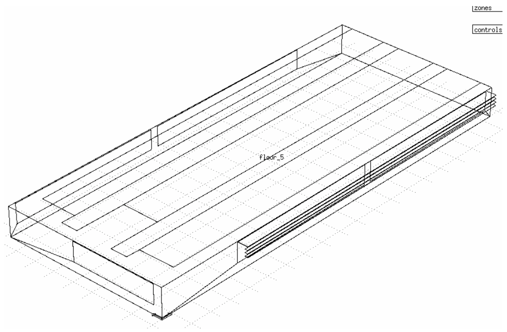

Figure 2: The ESP-r model of the building 5th floor.

to 4 K during extreme summer periods.

2. EARLY DESIGN SIMULATIONS

In the early design phases of the building computer simulations were carried out to prove the concept of night cooling ventilation and to study some other effects.

A section (2,5x15,5x2,7 m) of the open-plan offices was modeled in the ESP-r simulation environment (Fig. 2).

The simulation was carried out in two steps. The first aimed to find out if night ventilation without mechanical cooling would be able to guarantee acceptable thermal comfort. If it wouldn't, then the next step was to assess the necessary cooling capacity taking into account the building thermal mass as well as night ventilation effects.

Te predictions shows that the internal air temperature would be very often (202 hours) above the thermal comfort limits if there would be no mechanical cooling.

The mechanical cooling should be at least 0,9kW (23W/m^2) to guarantee acceptable thermal comfort in the office according to the early design simulation results. The early design simulations suggested that the high thermal mass and the night ventilation would decrease cooling energy consumption. However, there is additional cooling needed in order to obtain thermal comfort. Therefore a so-called "top cooling" system was subsequently applied.

3. BUILDING MONITORING

In the first year of operation there were many complaints from the open-plan office users; mainly about too high indoor temperature during the hot period of May 2002. Therefore measurements were carried out and the system performance was analysed. Finally it was found that the reason was not poor HVAC design, but poor realization. The system was not tested in cooling mode during commissioning and some components did not work properly. The heating coil valve was leaking and thus effectively the heating was on all the time. The fans had been operated just at half speed because of noise complaints in some offices. The night ventilation was not used at all. When the major problems were fixed and a night cooling regime was introduced, subsequent monitoring proved that the system functioned satisfactory.

4. THE SIMULATIONS MODEL CALIBRATION

The second stage of the work used a more complex simulation model for system optimization. For calibrating this model, there were three types of measured data available. Firstly data from the building energy management system. Secondly data acquired from long-term monitoring of inside temperature and humidity and from short-term detailed measurements of indoor temperatures and velocity distribution near the diffusers. Finally weather data from the CTU meteorological laboratory.

The fifth floor of wing C (37.9x15,7x2,7m) was modeled in ESP-r as one zone including all constructional details, shading properties and internal gains. The exposed ceiling and the uncovered floor are of concrete. The façade is insulated according to the Czech standard (u = 0,36 W/m^{2}K) and the double glass windows (u = 1,3 W/m^{2}K; g = 0,5).

The result of the building model calibration based on the measured data is the working day internal gains profile as presented in Figure 3. (The simulation does not respect summer time, when office hours start from 7 not from 6.). The real equipment gain is 34% of the nominal value.

Next, the building model was extended with an explicit plant system model. This model comprises ducts, heat recovery, fan and cooling coil. The plant model was calibrated as well. The calibration results (Figure 4) show similar inside temperature and cooling flux to the zone. When comparing simulation results with meas-

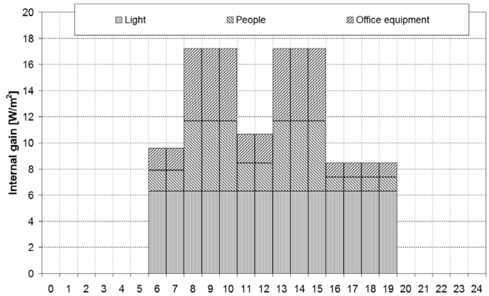

Figure 3: The internal gains profile for 1 day.

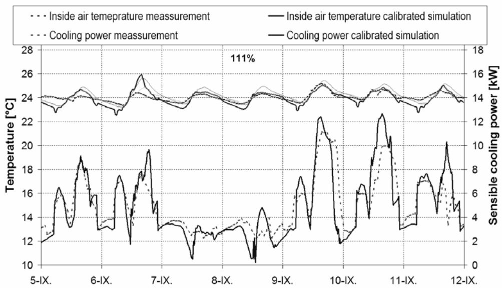

Figure 4: The building with plant system calibration results.

urements in a real building we should not expect a perfect fit. There are too many uncertain parameters (e.g. material properties) and unknown variables because they are not monitored (e.g. openable windows). Also the real system sensors are not very accurate. Finally, an office is not really a well mixed zone; at any point in time there may be air temperature differences within the office up to 1,5 K.

5. MODELING THE OPERATION STRATEGIES

The calibrated building and plant models were simulated using Prague reference year weather data to find out the operation schedule with lowest overall energy consumption. It is important to include the electricity consumption for fans and chiller (cooling water source). The overall COP of the chiller system was assumed to be 2.5 (usually 1,5-4). Fan electricity consumption grows exponentially with flow rate, therefore just comparing cooling energy consumption does not represent the systems properly. The energy consumption of the fan was calculated as a function of flow rate.

In total, ten operation scenarios were simulated. In the first six simulations various combinations of flow rates and time periods were tested. For the next five cases the cooling coil capacity was reduced.

Case 10 actually represents operation of the building without any cooling. For comparison, case FC represents the performance of the same building without thermally active ceiling (added insulation on inside surface) and floor (carpet) when just a minimum of fresh air is supplied during working hours and cooling is provided by a fan-coil system.

6. RESULTS ANALYSIS

Changing the flow rates during the day and night does not influence the overall energy consumption strongly as can be seen from the Cases 0 to 5 results in Figure 5. Although the coil cooling energy consumption decreases considerable with higher flow rates, the higher energy consumption of the fan results in small differences in total energy consumption. In the cases with limited cooling coil capacity (Cases 6 to 10), the overall energy consumption decreases. In the cases when the cooling capacity was limited to 5 kW or to zero (Cases 8 and 10) the inside air temperatures are above the thermal comfort limits for a significant part of the summer, which is not acceptable (Figure 6).

Finally Case 9, in which a reduced flow rate of 1,06 kg/s is applied over 24 hours during week days and the cooling coil capacity is limited to 7 kW, can be recommended. For the given weather data, the total energy consumption is estimated at 11,6 MWh representing a

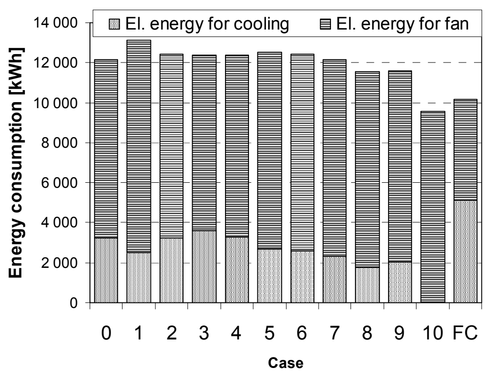

Figure 5: Comparing el. Energy consumption over whole summer for all simulated test cases.

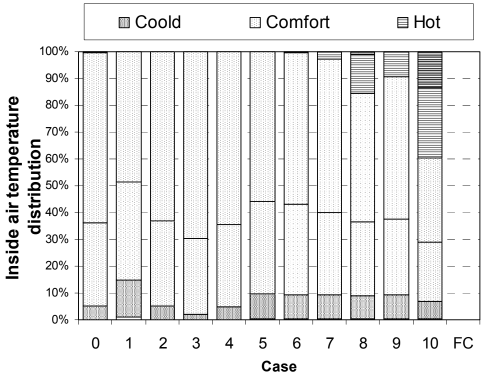

Figure 6: The inside air teperature distribution.

12% reduction compared to Case 1. The inside air temperatures would not exceed 28°C at any time.

From the results for Case FC (fan-coil and building without active thermal mass) it is clear that the cooling energy consumption would be much higher for the fan-coil system, but the overall electricity consumption would be the lowest of all cases. The chiller capacity for the fan-coil system is 27 kW, it is almost 3 time more than the optimized top cooling system. The investments and maintenance costs for the chiller will be therefore much higher.

7. CONCLUSION

To design low energy cooling using night ventilation, computer simulation is a very important tool for predicting comfort without mechanical cooling and/ or the required cooling capacity for hybrid systems.

Internal gains from office equipment are very important in the thermal balance of office buildings. In reality the thermal gain from office computers and such is much lower than the nominal power input on the name-plate.

Design and commissioning of low energy systems is usually more complex than for standard HVAC systems. It requires better cooperation of all participants in the building design, construction and maintenance. Unfavourable experiences with some realized systems are mostly due to the lack of information exchange. Sometimes during construction a system is simplified in such a way that it is not able anymore to work properly. Also, the systems are often operated without any knowledge about its principles.

In top-cooling and all-night ventilation systems the electrical energy consumption of the fans is very important. Due to the relatively high COP of mechanical cooling systems, even large cooling energy savings by night ventilation can be counter balanced by the electrical energy consumption of the fans. The system should be designed with low pressure losses in order to reduce the fan energy consumption.

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