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COMPUTER SIMULATION FOR BETTER AIR-CONDITIONING AND VENTILATION DESIGN OF INDUSTRIAL HALLS

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Abstract: The paper deals with the use of computer simulations both for the design support of HVAC systems development in existing industrial buildings. There is presented selected industrial hall and its HVAC systems concept. The computer simulation using ESP-r software for different rates of ventilation by outdoor air helped to design an air-conditioning system, which comprises of daytime top cooling and night ventilation by outdoor air combined with accumulation of cold in building constructions.
Capacity of mechanical cooling was decreased to more that 50% comparing to original design based on manual calculation for peak loads. The importance of internal gains measurements and investigation for industrial halls is presented as well.

Keywords: energy, comfort, industrial hall, simulation

1. 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 working spaces is increasing in Europe, especially in the Czech Republic. 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 (Santamouris 1996, Heap 2001) .

2. 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.
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 main method for solving such a buildings and systems 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 the presented studies the ESP-r simulation software was used; in some cases combined with other software.

3. INDUSTRIAL HALL

This case study deals with energy balance and verification of indoor environment in existing factory building in Czech Republic. Objective of the energy simulation is to predict indoor environment parameters in the building based on the knowledge of internal heat gains. Up to now for industrial hall just heating and ventilation without cooling in summer was common praxis. Due to some very hot summer's (2003,2006) and request for better conditions for workers and technology leads to using air conditioning for industrial halls. The common design based just on the nominal internal gains and external gains leads to over sizing of cooling capacity and finally to high energy demand for cooling. More complex design, based on detailed analysis of internal gains and dynamic building model helps to rapidly decrease of investments and save a lots of energy.

4. THE BUILDING

The solved hall is an existing single-storey building located in the Czech Republic close to Germany borders. Main unit of the building is a hall with kilns. The model of the hall deals with kiln hall energy balance with focus on summer extremes. The building constitutes of steel concrete basement slab and internal walls, which are made of bricks. Ceiling of the hall is insulated and there is a roof space above it. From day lightning reasons the western and eastern facades are fenestrated.

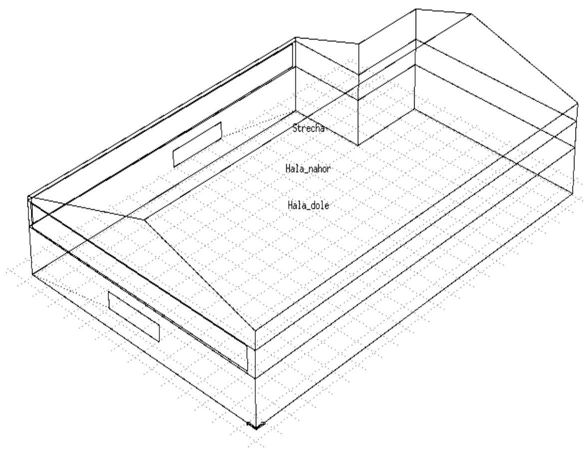

Figure 1: Model of the hall in ESP-r

5. VENTILATION AND INFILTRATION

Mechanical ventilation of the kin hall was considered for energy simulations. In total 50 000 m^3/h (16,67 kg/s) of air was supplied into the hall. If outside air temperature was lower than 23 °C only outside air was supplied; if outside air temperature was higher than 23 °C only 16 000 m^3/h (5,33 kg/s) of outside air was supplied and the rest i.e. 34 000 m^3/h (11.33 kg/s) of air was recirculated from the upper part of the hall.
Combustion air sucked from the lower parts of the hall was exhausted via smoke flue to the outside (10 000 m^3/h, i.e. 3,33 kg/s). The rest of air was exhausted to the outside from the upper parts of the hall.

6. INTERNAL HEAT LOAD OF THE BUILDING

Thermal environment in the hall was analyzed for the common activity in the hall. Since influence of interior heat load is significant, its determination was done as accurately as possible. The determination of internal heat load of particular machines was based on three correction coefficients:

- The coincidence factor reflects operation simultaneity of individual machines. The operation of electric furnace was continuous and the coincidence coefficient was set to 1.
- The utilization factor takes into account actual operation consumption that could significantly differ from maximum nameplate value. The total power input of selected electric furnace on the hall was corrected (based on field experiment) by average utilization coefficient of 0,3.
- The residual coefficient is applied in cases when part of heat gain is not transferred into the hall (and it is directly extracted e.g. by exhaust hood or by water cooling). The electric kilns were connected to smoke exhaust and considered by residual coefficient. 2000 m^3/h

of air was exhausted from each kiln with temperature of smoke of about 140 °C (measured). The residual coefficient was 0,34.

Six electric furnaces were considered in numerical predictions with nominal power input of 360 kW each.

Isolated ducting for venting is located in the upper part of the hall. Thus part of the heat exhausted from the kilns was transferred to the hall space through faces of ducting. Average exhausted gas temperature was 140 °C, air temperature in the upper part of the hall was anticipated of 30 °C.

Tab. 1: Internal heat load of the hall

Heat source	**Internal heat load**	
	kW	**W/m²**
Technology (kilns)	208,1	196,2
Technology (venting)	9,2	8,67
Lighting	10,37	9,8
Workers	1,8	1,7
Total	**229,5**	**216,4**

7. MODELED ZONES

Since the focus was on energy balance in the hall (where temperature stratification exists) a three-zoned numerical model was designed:
lower part of the hall (up to 3,9 m) -1061 m^2 4140 m^3; upper part of the hall 1061 m^2 2282 m^3; roof space above the hall. The shape of zones was identical to existing hall.

8. RESULTS AND DISCUSSION

According to Czech standards that determines conditions for health protection of workers, based on type of work. The results were analyzed for thresholds of operative temperature mean of 26 °C and maximum of 32 °C.
The result sets are represented for 4 variants of operation and leads to optimize cooling capacity of the chiller.

Variant 1

It is air conditioning when the operative temperature is usually around 26 °C and its maximum is 26,4 °C. Required working thermal conditions were provided in the occupied zone for the whole summer period. The required sensible cooling output was max. 232,5 kW and consumption of the cooling 152 MWh. Relative humidity was in a range of 55 and 80 % and the values over 55 % were only rare. Results show that the use of adiabatic cooling would not lead to reduction of required cooling output and only marginally reduce annual energy consumption by about 8 %.

Variant 2 (figure 3)

The cooling output was reduced to 186 kW and air temperature in the zone increased in summer extremes (up to 26°C) as well as the analyzed operative temperature when the. Maximum operative temperature was 29,1 °C, however operative temperature of 27 °C was exceeded only for 181 hours i.e. for 5 % of the summer. Operative temperature fluctuated mainly below 26 °C (78 % of the summer). Since the maximum tolerable temperature is 32 °C such working thermal conditions could be designated as acceptable. Thus it is not necessary to reduce the working time or to shorten working shifts. The cooling consumption was 146 MWh.

Variant X1

This variant with very limited output of mechanical cooling (50 kW sensible cooling output) and with intensive outdoor air supply (50 000 m^3/h) shows the air temperature in the hall were below 26 °C for a half of summer period and only 7 % of summer above 32 °C. Maximum temperature was 36 °C.

Variant X2

Tepresenting the current stage when the hall is cooled by reduced cooling output 50kW and ventilated by 16000 m^3/h of outdoor air. This Variant showed unacceptable thermal working conditions in the hall. Air temperature exceeded 32 °C for most of the summer period and in extremes reached up to 46 °C. This corresponds to current stage measurements.

9. CONCLUSIONS

In order to provide high standard of thermal working environment the cooling output of cooling coil is recommended to be 200 kW.

Required total supply and combustion airflow is 50 000 m^3/h.

Adiabatic cooling will not reduce required cooling capacity and it may save up to 8 % of running costs. Thus adiabatic cooling is not recommended in this case.

The study helps to decrease the cooling capacity and prevent the over sizing of the whole system, original concept was based on nominal power input of kilns and no dynamic behavior and capacity of chiller was 500 kW.

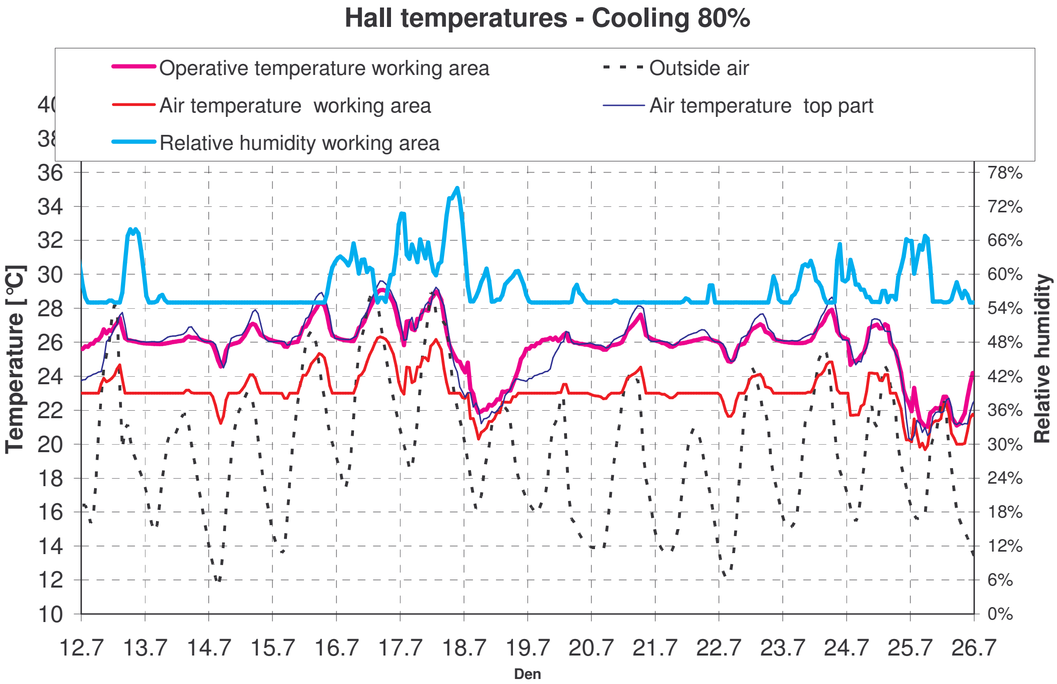

Figure 3: Temperatures in the kiln hall variant 2 for selected period

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