Knowledge from running of air conditioning in clean spaces

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ABSTRACT

This text contains attainments from indoor climate and air conditioning equipment monitoring in clean rooms in the public health service. The editor is designer of HVAC systems in the modern hospital near Brno in the Czech Republic. The text includes the experiences from the design phase as well as from the function the hospital. Monitoring of the HVAC systems enables during 2 years operation efficiency evaluation of heat recovery system from waste air. We are able to evaluate its economy effect. And benefit of heat recovery system depends of course of outdoor climatic conditions.

INTRODUCTION

The general requirement for energy consumption lowering in buildings includes also the requirement to bring down the energy consumption for heating. Czech technical standard for thermal protection of buildings is permanently innovated and the requirements for thermal-technical properties of buildings are strict. It is necessary to deal with lowering the heat losses by ventilation, especially in buildings where the air change rate is higher. By current standard for the envelope of the building the heat loss by ventilation is higher than the heat loss caused by transmission already for air change equal to one. That is the reason to intensify dealing with systems for energetic demand for ventilation lowering – systems for heat recovery. Other possibilities that follow are related to the operation of the equipment – the choice of the optimal temperature of the inlet air with respect to the required indoor temperature, taking the advantage of the operating hours of the equipment by using damping mode with lowered air supply. If it is not possible to set the equipment away in non-operating hours due to hygienic reasons, it is advisable to lower the air temperature (similarly as when heating) at damping mode.

The eldest and simplest method of heat recovery of air is mixing when a part of the airflow circulates and another part is mixed with the outside air. This is not a fortunate solution, when ventilation is concerned, especially for large systems operating a greater number of rooms. The air circulation spreads the noxious agents from a single room into the other areas of the building via air conditioning. This is evident e.g. while air-borne spread of cold disease. Therefore the mixing of air of ventilation and air conditioning systems should be nowadays replaced by hygienically more favorable methods.
EXPERIMENT AND METHODOLOGY

Most frequently used exchangers for recycling of heat from outlet air are plate heat exchangers in counter-flow or cross-flow connection. These particular heat exchangers in air conditioning units that operate clean spaces were subjected to detailed observation while running in reality. A special attention was devoted to these effects:

- Efficiency of heat recovery from outlet air. Based on measurements of necessary variables by Measurement and Regulation system the efficiency of heat recovery was calculated and heat savings were evaluated.
- Heat loss by transportation of air by piping and in air conditioning unit.

Individual fields were elaborated experimentally based on measured variables provided by Measurement and Regulation system of the object, some variables were derived and calculated. The system measures and saves the values in the interval of 6 minutes.

HEATING OF THE AIR IN THE RECUPERATOR AND HEAT SAVINGS

Air conditioning equipment from two operating rooms was chosen for monitoring. The airflow of the inlet air is 6200 m³/h; the airflow of the outlet air is 5750 m³/h.
The building control system permanently measures and saves the temperature of the outer (suction) air, inlet and outlet air and waste air behind recuperator. The humidity of outlet air is measured as well. The variables are indicated on fig. 1. The air temperature behind the heat exchanger on the inlet airside was calculated from equality of heat flows of inlet and outlet air:

\[
V_p(t_e^i - t_c) = V_o(t_i^o - t_i^o)
\]  

(1)

Airflows are determined from measurement of speed in piping made by testcrosses. Based on this measurement the speed of the fan is adjusted in order to reach constant airflow by means of conversion transducer.

Because of this the airflow in piping is constant without the influence of pressure relations in piping network. The measurement of speed is made on the treated inlet airside and the outlet air leaving the room before the AC unit side. The temperature of inlet and outlet air is similar; the difference is not bigger than 5 K. Hence the influence of different thermal capacities of airflows and their densities can be neglected.

An individual problem is the condensation of water vapor on the outlet airside while observing the plate exchangers efficiency. No moistening of inlet air was applied in monitored period; therefore the humidity of outlet air was low (under 30%, commonly about 25%, consequently dew point lower than 5 °C). Because of this low humidity and assumed efficiency of heat recycling up to 60% it was possible to exclude the condensation of water vapor on the exchanger.
The graph representing the temperature relationships while cooling of the waste air on the plate exchanger is shown on fig. 3. We can also see the outlet air temperature variation corresponding to room temperature variation. In operation period the room temperature is 24.5 °C, otherwise 19.5 °C. In regard to high air change rate (23x per hour) the temperature rise and drop is very fast, temperature difference of 6K in operation field is balanced in 15 minutes. Lowering of temperature in non-operating hours is another advisable saving measure. However it is necessary to synchronize the temperature modes of ventilation (air conditioning) system and heating system. From measurement it is obvious that if the heating elements are not adjusted accordingly, the heating system automatically increases its power to compensate the loss by ventilation. Thus the temperature of outlet air remains the same in operating and non-operating hours.

It is possible to calculate the heat savings based on measured and calculated variables in the formula 2:

\[ Q = \int_{\tau} V_p \rho c (t'_e - t_e) d\tau = \int_{\tau} V_o \rho c (t_i - t'_i) d\tau \]  

(2)

At the average outer temperature is 3.0 °C the thermal energy savings of heat recovery system by 50%.

It is necessary to mention another factor. When using the heat recovery system, the Building control system should contain control of the plate exchanger bypass and provision of the antifreeze safety. But if the heat recovery system substitutes air mixing, the mentioned modifications of MaR are equivalent to the control of mixing valve.

Thermal efficiency of the exchanger is defined by the formula [3]:

\[ \eta = \frac{V_o (h_i - h'_i)}{V_o h_i - V_e h'_e} = \frac{V_e (h'_e - h_e)}{V_e h'_e - V_e h_e} \]  

(3)

Above the assumption makes simplified formula:

\[ \eta = \frac{t_i - t'_i}{t_i - t_e} \]  

(4)

In monitored period the outer temperature varied from -1 °C to +5 °C. The average efficiency of the exchanger was 50%. This low efficiency is given by low humidity of outlet air (to 30%), so that there is no condensation of water vapor by cooling of outlet air. For such conditions the manufacturer states the efficiency to be 52%. It is necessary to respect the real efficiency while thinking about the importance heat recovery equipment saves 1,18 GJ of thermal energy per day. If the thermal energy is acquired from a central heat supply system the savings per day can be enumerated to 13 Euro. We assume this day as a representative day for whole heating period. For a total number of 195 days would the year savings of one heat recovery unit be 2 555 Czk. The length of the heating period is derived from average monthly temperatures according in Czech Republic.

The pressure loss of the chamber of the plate exchanger in optimal operating conditions does not exceed 200 Pa, in monitored case it is 120 Pa. Total pressure of a supply fan is 1 200 Pa, which means at given airflow and efficiency of the fan the power of 2,79 kW. At the decrease of supply pressure by 120 Pa the required power drops to 2,48 kW. The real consumption of energy for the fan driving is determined according to the engine power assigned to the fan. The lowering of total pressure of the fan would mean in this case the lowering of required
engine power from 4.0 to 3.5 kW. The equipment runs 24 hours per day, 10 hours of it to 100% and 14 hours to 50% air power. In this operating mode is the difference of electrical energy consumption 7.8 kWh/day for supply fan and 2.3 kWh/day for outlet fan. The difference of electrical energy consumption makes 2 890 kWh per year. The operation of the fans in the AC unit without the plate exchanger would be cheaper by 286 Euro, considering market price of electrical energy. The increase of supply pressure of fans lowers of heat recovery. In despite of relatively low efficiency the thermal energy savings mentioned above are significant.

HEAT LOSS BY PIPING AND IN AIR CONDITIONING UNIT

If we look at possibilities for savings of thermal energy for air conditioning, it is necessary to be concerned with heat losses in air conditioning distribution system. Average values of heat transmission coefficient shows table 1.

Tab. 1 Heat transmission coefficient of air conditioning units and their insulated piping

<table>
<thead>
<tr>
<th>Insulation</th>
<th>Heat transmission coefficient (W/m²K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC unit panel cover PUR panel 50 mm</td>
<td>0,57</td>
</tr>
<tr>
<td>AC unit panel cover PUR panel 25 mm</td>
<td>0,95</td>
</tr>
<tr>
<td>Steel piping with insulation from mineral wool 60 mm</td>
<td>0,67</td>
</tr>
<tr>
<td>Steel piping with insulation from mineral wool 40 mm</td>
<td>1,0</td>
</tr>
</tbody>
</table>

The heat loss through AC unit panel cover is neglected if the AC unit is placed in interior heated environment. The thermally treated air passes only through short part of the unit (exchangers are usually placed at the end of the formation) and the heat loss does not exceed 50 W. Fig. 2 shows thermal image of an AC unit. Even though is the total heat loss not significant, it is obvious that the temperature field of the outer cover of the panel corresponds to the supply air temperature. The AC unit is modular, made of chambers. From the thermal insulation point of view are the critical places connections of the chambers, since there are the stiffening elements. The temperature difference in the middle and in corners is 5 K by temperature difference of 19 K between the warm (waste) air and fresh (outer) air. Condensation of water vapor can occur under unfavorable thermal moisture conditions. The piping in the machine room has thermal insulation of the thickness of 60 mm. besides heat losses and risk of condensation it is necessary to take into account the noise propagation. At the temperature difference between the air in the machine room and in the piping 10 K is the heat loss for 50 m² of the heat transfer surface of the piping 330 W. For average conditions (above mentioned example) this heat loss does not mean a change greater than 0,3 K in the temperature of supply air. Thermal imagining proved a good quality of the insulations, which should be nowadays standard in HVAC field.
Current design standard of thermal resistance of constructions of building envelopes ensures that even in unheated spaces of buildings the temperature approaches the temperature in surrounding rooms. In ordinary circumstances the piping does not pass though different spaces concerning temperature. If the temperature of the supply air does not differ from the temperature of the surroundings by more than 4 °C it is not necessary to insulate the piping. In running of public health services the ventilation systems usually take over the role of air conditioning and therefore the piping is insulated because of the summer temperature conditions. We can summarize that air transportation by piping is no more a source of heat losses.

RESULT

From all of the heat losses in air-conditioning equipment that was analyzed above is the most significant one a heat loss by ventilation, which can be effectively lowered by means of heat recovery system. The values presented in this article were obtained by monitoring of real air conditioning equipment. Air conditioning in health service is specific with regard to operation time and higher air change rates. These are favorable circumstances for usage of plate exchangers that ensure hygienically clean running by separation of the inlet and outlet airflows. In this case study were found annual savings of thermal energy under real climatic conditions in the CR 2 270 Euro. Considering the price of a chamber with a plate exchanger to be 3 100 Euro, the payback of this measure is very short.

Another suitable measure is consequent respecting of working hours in attended spaces. Only then it is possible to use lowered air supply and lowered temperature in damping time. Mutual correspondence between set values of air conditioning and heating is essential.

![Thermal relations of a plate exchanger](image-url)

Fig. 3 Thermal relations of a heat recovery exchanger in Januar 2006
DISCUSSION

Efficiency off-heat reverse obtaining can markedly be lowered by low outdoor temperature with effect antifreeze exchanger safety. By temperature fall of waste air below 5°C is outdoor air input partly or completely bypass. Surface temperature of exchanger could be in this time lower then 0°C (figure 4). Heat exchanger is for this time off the function. Temperature 5°C waste air can be reach with outdoor temperature about -7°C (figure 3). The real efficiency with low outdoor temperatures is accordance with lower regulating antifreeze safety exchanger.

Fig. 4 Air and surface temperatures of exchanger

Fig. 5 Thermal relation of heat recovery exchanger by antifreeze safety
NOMENCLATURE

Variables:
V ... airflow (m³/h)
Q ... heat power (W)
t ... temperature (°C)
h ... enthalpy (kJ/kg)
τ ... time (s)

Indices:
i ... inner
e ... outer
Ψ ... efficiency (%)
o ... outlet (air)
p ... inlet (h)

REFERENCES