HEAT RECUPERATION IN VENTILATION SYSTEM OF BASEMENT LABORATORY

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Abstract. Basement spaces in many university buildings because of the worse microclimate conditions are most commonly used for warehouses in which workers or students cannot be. In many buildings there are also problems occurring with the underground moisture that penetrates from the surrounding terrain into the external walls, which thus become wet. The aim of this paper is to show the possibility of microclimate improvement in the basement room by forced ventilation, so that it is possible to use this room for the purpose of teaching and research laboratory activities. Due to the need of permanent intensive ventilation to exhaust the chemical pollutants and supply the fresh air, the ventilation system is designed to achieve the energy savings during the winter by means of heat recovery from the exhausted heated air into the cold incoming fresh outdoor air. This paper summarizes the experience in use of this ventilation system with heat recovery, which could enable to solve well similar problems in other underground buildings.

Keywords: chemicals, energy, measurement, temperature.

Introduction

The aim of this paper is to show the possibility of microclimate improvement in the basement room by forced ventilation, so that it is possible to use this room for the purpose of teaching and research laboratory activities. Due to the need of permanent intensive ventilation to exhaust the chemical pollutants and supply the fresh air, the ventilation system is designed to achieve the energy savings during the winter by means of heat recovery from the exhausted heated air into the cold incoming fresh outdoor air. This paper summarizes the experience in use of this ventilation system with heat recovery, which could enable to solve well similar problems in other underground buildings.

Materials and methods

This research work was carried out in the laboratory of the Faculty of Engineering at the Czech University of Life Sciences Prague. The laboratory consists of three connected rooms situated in the first basement floor. The first room is storage, the main and biggest room is used mainly for the teaching and the third one is used for experimental work, mainly for adhesive bonding. The rooms have the following dimensions: total volume of the room is O = 357 m^3 and inside maximum can be 26 persons.

The investigated laboratory is used for research and teaching purposes, therefore sanitary conditions for the students and staff must be respected. The requirements of health and safety at work are summarized in [1]. The rules for work in the lab ranked according to the total average energy expenditure $M \leq 80$ $W \cdot m^{-2}$, work Class I, therefore, the air temperature should be in winter 22 ± 1.5 ºC if the expected thermal resistance of clothing is 1.0 clo (means the clothing insulation of typical menswear suit of people working inside the laboratory), and relative humidity of air from 30 to 70 %. Natural ventilation is insufficient in this type of laboratory and therefore mechanical ventilation should be applied to ensure a year-round health of workers. The fresh air must be filtered and heated in winter.

Chemicals used in the laboratory are: industrial solvent perchlorethylene (tetrachloetylen), acetone, adhesives GLUEPOX rapid F (2-piperazin-1ylethyamin, benzyl alcohol, bisphenol A) contains benzyl alcohol), CHS-EPOXY 324 (contains bisphenol A), ethanol, toluene, and hardener P11 (diethylene). There is no doubt about the harmful effects of the environment on the adhesive bond [2], each environment is of specific properties which basically influence the entire strength and reliability of an adhesive bond [3; 4], therefore the control of microclimate is important as well.

The ventilation system is installed under the ceiling of the ventilated rooms and partly also in the corridors and in the workshop, which is on the other part of the corridor. The ground plan of the laboratory and the ventilation system are presented in Fig. 1.

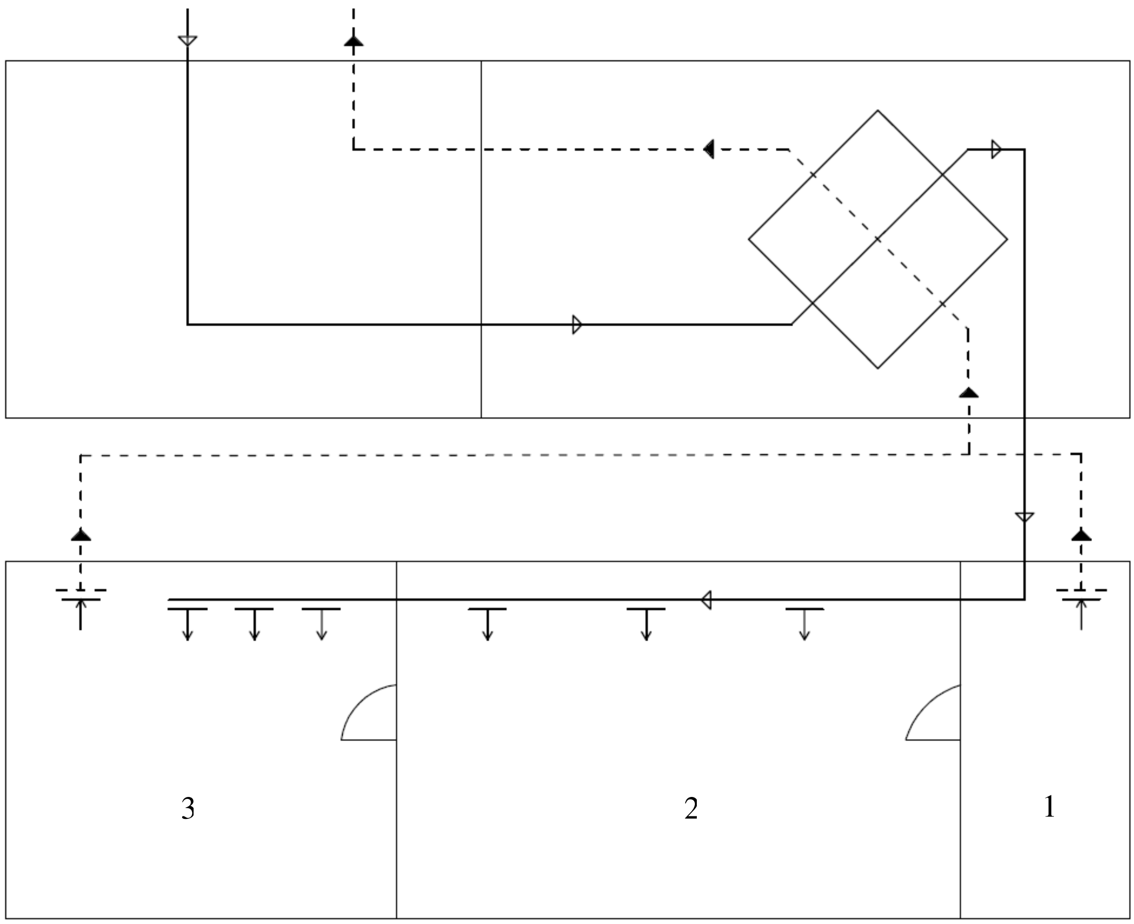

Fig. 1. **Ground plan of the laboratory:** 1 – storage, 2 – teaching area, 3 – experimental area

The central part of the ventilation system consists of a compact ventilation unit with heat recovery DUPLEX-BT 3000, air ducts for distribution and discharge for air together with air inlets and outlets. Opened uncovered ventilation unit is presented in Fig. 2. The maximum capacity of radial fans for inlet and outlet is the same 1440 $m^3 \cdot h^{-1}$; the static pressure of the inlet fan is 383 Pa and of the outlet fan 310 Pa. Control of the ventilation intensity is manual, according to the operator's subjective opinion. Typically it is functioning on an average value (level I), or to the maximum (level II). Internal filters class G4 for inlet and outlet air are made from synthetic materials; the cross recuperative heat exchanger is assembled from thin plastic plates.

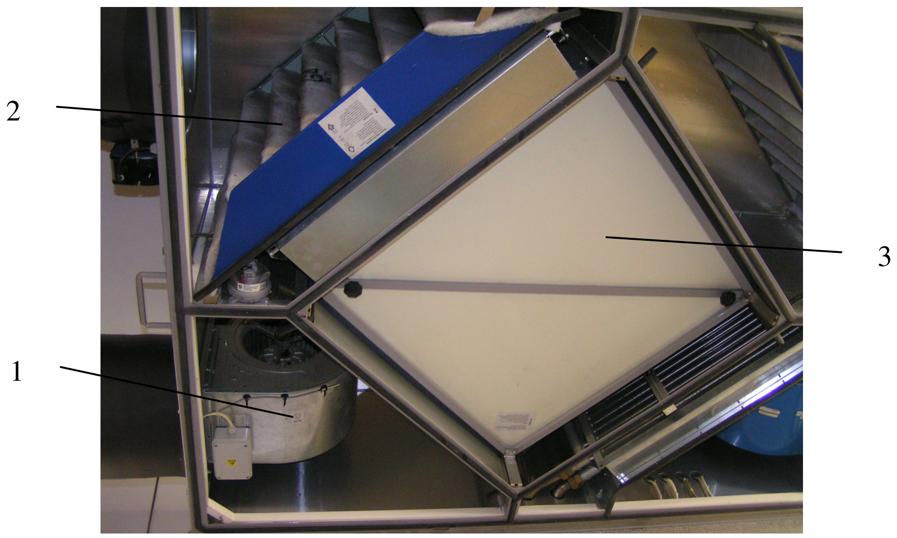

Fig. 2. **Ventilation unit:** 1 – fan; 2 – filter; 3 – heat exchanger for recuperation

The temperatures of incoming air after the exchanger (t_e') and the temperatures outside and inside the building were measured as well. Air temperatures were measured by thermocouples NiCr-Ni type K installed in the ventilation system (the air flow through the whole system: in the inlet, in different parts of heat recuperation systems, in the outlet etc.). Furthermore, by data loggers ZTH65 temperature and humidity were measured with registration during the experiments. Parameters of ZTH65 are: temperature operative range -30 to +80 ºC with accuracy ±0.4 ºC and operative range of relative humidity 5-95 % with accuracy ±2.5 %.

The results of the measurements were used to calculate according to [5] the thermal efficiency η_R of the heat recovery (equation (1)). The heat flux Q_R gained from the heat recovery is calculated according to equation (2). It is supposed that the airflows, density (ρ_a) and specific heat (c_a) of the outgoing air and incoming air are the same.

$$\eta_R = \frac{(t_e' - t_e)}{(t_i - t_e)}, \qquad (1)$$

where η_R – thermal efficiency of heat recovery, -;
t_e' – temperature of incoming air after the exchanger, ºC;
t_e – temperature of external incoming air before the exchanger, ºC;
t_i – temperature of internal air before the exchanger, ºC.

$$Q_R = V_e \cdot \rho_a \cdot c_a \cdot (t_e' - t_e), \qquad (2)$$

where Q_R – heat flux gained from the heat recuperation, kW;
V_e – flow of incoming air, $m^3 \cdot s^{-1}$;
ρ_a – density of air, $kg \cdot m^{-3}$;
c_a – specific heat of air, $kJ \cdot kg^{-1} \cdot K^{-1}$.

The indoor temperature and humidity in the laboratory were measured by the sensor FH A646-21 including the temperature sensor NTC type N with operative range from -30 to +100 ºC with accuracy ±0.1 K, and air humidity by the capacitive sensor with operative range from 5 to 98 % with accuracy ±2 %. All data were measured continuously and stored at intervals of one minute to the measuring instrument ALMEMO 2590–9 during the measurement. The concentration of CO_2 was measured by the sensor FY A600 with operative range 0-0.5 % and accuracy ±0.01 %.

The total concentration of air dust was measured by a special exact instrument Dust-Track aerosol monitor. After the installation of different impactors the PM_{10}, PM_4, $PM_{2.5}$, PM_1 size fractions of dust were also measured. The measured dust inside the offices is not aggressive, it has properties as house dust, therefore, as a criterion for evaluation of the measured values the limit level of outdoor dust was selected, which is 0.050 $mg \cdot m^{-3}$ (50 $\mu g \cdot m^{-3}$).

Dust that is released into the surrounding air during preparation of the samples corresponds to the material used for adhesive bonding. Most often it is metal, plastic or wood. According to the type of material, dust has specific characteristics to which the properties respond. According to [1], there can be dust with nonspecific effects (metals) or irritating effects (plastics and wood). For these types of non-metal dust there are prescribed Occupational exposure limits OEL of total concentration 5 $mg \cdot m^{-3}$; OEL for metals (Fe and Al alloys) are 10 $mg \cdot m^{-3}$.

Results and discussion

1. Calculations of the air flow

Assuming steady conditions with a uniform distribution of pollutants in space the required volume of air flow for ventilation is determined according to equations (3) and (4). According to [1], it must be 50 $m^3 \cdot h^{-1}$ minimum amount of air entering the workplace for an employee performing work classified to Class I. In extra load space by odors the minimum amount of air has to be increased. The total amount of the outdoor air flow for ventilation V_{min} supply is determined from the highest number of people simultaneously using the ventilated space and from the ventilation rates of fresh air per one person according to equation (3).

$$V_{\min} = n_1 \cdot d, \qquad (3)$$

where V_{min} – required minimal capacity of air flow for ventilation, $m^3 \cdot h^{-1}$;
n_1 – number of persons in the room, units;
d – ventilation rate of fresh inlet air, $m^3 \cdot unit^{-1} \cdot h^{-1}$.

The second method of calculation of the air flow rate is only very approximate. The air flow calculated according to the prescribed air exchange V_I supply is determined from the prescribed air exchange I of the ventilated room with the volume O according to equation (4).

$$V_I = I \cdot O, \tag{4}$$

where V_I – air flow according to the prescribed air exchange, $m^3 \cdot h^{-1}$;
I – prescribed air exchange of the room, h^{-1};
O – volume of ventilated room, m^3.

The results of airflow calculated according to all described methods are summarized in Table 1. The final results of real airflows supplied to and discharged from the ventilated laboratory are the same 1440 $m^3 \cdot h^{-1}$ which should be sufficient for the biggest ventilation rate level II if the pollution of the air is maximal (intensive research work and teaching activity). During normal conditions level I of ventilation can be used, approximately 720 $m^3 \cdot h^{-1}$ when the pollution inside the room is not so intensive.

Table 1

Calculated values of the air flows

-	V_{min}, $m^3 \cdot h^{-1}$	V_I, $m^3 \cdot h^{-1}$
According to the equation	1	2
Airflow rate	1300	1607

2. *Measurement of microclimatic parameters in the laboratory*

The results of measurement of the main microclimatic parameters in the laboratory are presented in Table 2. The air temperature should be in winter 22 ± 1.5 ºC for normal working conditions, and relative humidity of air from 30 to 70 %. The readings of temperature and humidity during the ventilation at I and II levels are within the specified values and meet the requirements of relevant standards and regulations. The positive influence of ventilation on the concentration of noxious gases is obvious from the decrease of CO_2 concentration in Table 2.

Table 2

Microclimatic parameters in the laboratory

Ventilation	t_e	RH_e	t_i	RH_i	CO_2
-	°C ± SD	% ± SD	°C ± SD	% ± SD	% ± SD
I level	3.73 ± 0.62	63.30 ± 3.20	20.83 ± 0.14	29.68 ± 1.44	0.038 ± 0.006
II level	5.36 ± 0.79	57.03 ± 2.38	21.28 ± 0.06	26.60 ± 0.59	0.033 ± 0.000

SD – Standard deviation

The dust concentration in the laboratory was very high. Principal results of dust measurement are summarized in Table 3. Inside the laboratory without ventilation the average concentration of total dust pollution was very high, nearly 0.2 $mg \cdot m^{-3}$.

The prescribed occupational exposure limits OEL of total concentration for all types of dust were not exceeded, but if there is compared as a criterion for evaluation of the measured values the limit level of outdoor dust, the concentration of all fractions was higher than the limit level 0.050 $mg \cdot m^{-3}$ (50 $\mu g \cdot m^{-3}$). The main part of dust particles were small fractions. About 81 % of dust was size fraction PM_1 which can penetrate into the alveoli and cause health problems.

Increased ventilation on level I and later on level II reduced strongly the dust concentration but the limit level 0.050 $mg \cdot m^{-3}$ was exceeded in total concentration of dust and also of all fractions in both cases of ventilation levels.

Table 3

Total dust concentration and concentration of dust fractions in the laboratory

Ventilation	Total	PM_{10}	PM_4	$PM_{2.5}$	PM_1
-	$\mu g.m^{-3} \pm SD$	$\mu g.m^{-3} \pm SD$	$\mu g.m^{-3} \pm SD$	$\mu g.m^{-3} \pm SD$	$\mu g.m^{-3} \pm SD$
0	198 ± 12.4	189.6 ± 6.3	189.4 ± 4.4	182.1 ± 5.4	160.2 ± 4.8
I level	115.3 ± 5.1	103.9 ± 4.6	98.6 ± 3.7	95.9 ± 4.0	88.4 ± 3.2
II level	92 ± 3.5	91.8 ± 2.7	90.1 ± 1.8	85.5 ± 1.6	81.5 ± 2.2

SD – Standard deviation

3. Measurement of heat recovery in ventilation

The function of the system for heat recovery equipped by the heat exchanger for energy recuperation was tested also in both levels. The efficiency of heat recovery η_R calculated according to the equation (1) for measuring the time in the ventilation levels I and II is expressed in the graph in Fig. 3. The heat flux Q_R gained from the heat recovery and calculated according to equation (2) is in Fig. 4 also for both levels of ventilation. The first part of graphs (approximately 1 hour there was ventilation at level I, and the second part approximately since the 65th minute till 90th minute at level II.

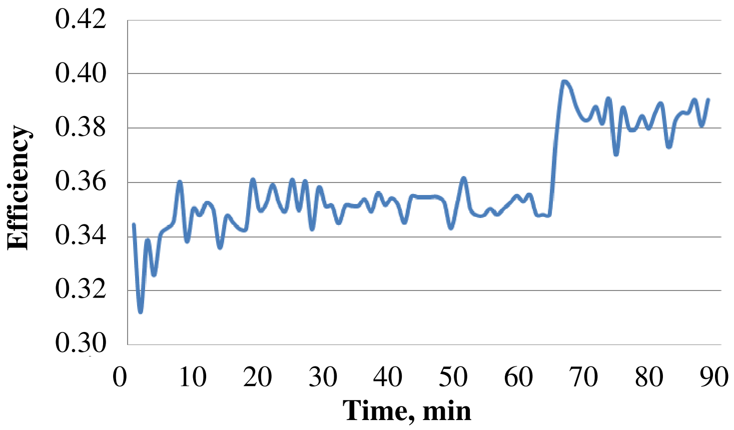

Fig. 3. **Efficiency of heat recuperation**

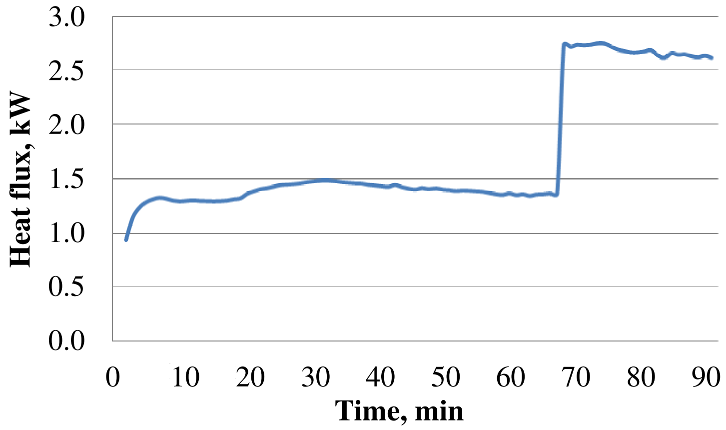

Fig. 4. **Heat flux gained from the heat recuperation**

The main statistical results of the efficiency of heat recuperation η_R and heat flux Q_R gained from the heat recovery are summarized in Table 4. Bigger airflow (level II) increased slightly the average efficiency of heat recuperation from 0.349 to 0.38, which resulted together with bigger airflow into the increased recovered heat flux from 1.37 to 2.68 kW. These results were achieved with partly polluted filters. It can be supposed that heat recuperation with new and clean filters enables to increase the efficiency and achieve bigger energy savings [5; 6].

Table 4

The efficiency of heat recuperation and heat flux of saved energy

Ventilation	η_R ± SD	Q_R ± SD, kW
Level I	0.349 ± 0.005	1.37 ± 0.06
Level II	0.38 ± 0.0049	2.68 ± 0.04

SD – Standard deviation

The data obtained from this experiment will be used for further research and evaluation of the impact of environment on test samples during preparation, processing and applications.

Conclusions

1. Underground windowless rooms can be used for teaching and research, if there is ensured intensive ventilation, adequate to the internal biological load or production of harmful substances. Increasing intensity of ventilation reduced the concentration of CO_2 from 0.038 to 0.033 % and total dust pollution from 198 to 92 $\mu g \cdot m^{-3}$.
2. The results of the measurement demonstrate that significant energy savings from 1.37 to 2.68 kW can be achieved with the use of recuperative heat exchangers for heat recovery from the outgoing air (heat recuperation from 34.9 to 38 %).
3. It is appropriate that the intensity of ventilation in these rooms would be set up automatically, e.g., according to the air temperature, humidity and CO_2 concentration.
4. Concentration of gaseous pollutants should be monitored by a safety control system with the relevant sensors.

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