Agronomy Research **14**(4), 1342–1350, 2016

Ventilation and microclimatic conditions in the laboratory of adhesive bonding

A. Krofová[1,*] and P. Kic[2]

[1]Czech University of Life Sciences Prague, Faculty of Engineering, Department Material Science and Manufacturing Technology, Kamýcká 129, CZ 16521 Prague, Czech Republic
[2]Czech University of Life Sciences Prague, Faculty of Engineering, Department of Technological Equipment of Buildings, Kamýcká 129, CZ 16521 Prague, Czech Republic
[*]Correspondence: kofovaa@tf.czu.cz

Abstract. The aim of this paper is to present the results of the research focused on the ventilation and microclimatic conditions in the laboratory of adhesive bonding. This special large underground laboratory is used for the research and teaching purposes during the whole year. The experiments provided in the laboratory require the use of different chemicals, adhesives and glues for the preparation of specimens for the testing various methods of adhesive bonding of metals and wood. There are intensively released chemical pollutants into the indoor environment of the laboratory during those processes. If there are taking place in the lab at the same time the classes with students (maximum 26 persons) there are also produced in that space products of the metabolism. To ensure the hygienic conditions for researchers and students, the laboratory must be adequately ventilated, but it is also necessary to ensure the desired thermal state of the environment. The results of measurements of indoor microclimate in this laboratory during the adhesive bonding processes are also presented in this paper. The experience and new knowledge useful for the future research and practical designs are summarized in the conclusions of this paper.

Key words: chemicals, contamination, dust, temperature.

INTRODUCTION

Adhesive bonding is increasingly used method of dismountable connection of components, parts and elements in various technical fields. New methods and new bonding adhesives under prescribed conditions are tested in the laboratory of adhesive bonding. Chemicals and adhesives containing various chemical components are used for these activities. This creates a very intensive pollution which must be removed. Indoor environmental quality should be kept within the prescribed limits, which are especially air temperature and humidity, concentration of chemical pollutants and dust. Critical period in terms of quality of the indoor environment is winter, because the ventilation is usually minimized (reduction of indoor-air cooling) (Kic et al., 2007; Zajicek & Kic, 2014).

There is no doubt about the harmful effects of the environment on the adhesive bond (Court et al., 2001). The main problem is to define the process and intensity of the changes in mechanical properties (Cidlina et al, 2014).

Adhesive bonds are very often applied in various climatic conditions and environments (Müller & Valášek, 2012; Müller, 2014). Each environment is of specific properties which basically influence entire strength and reliability of an adhesive bond (Müller, 2013; Müller, 2014).

During the transit or the storing the adhesives can meet much higher or lower temperatures than it is recommended by a producer (a sun radiation, a sun radiation through a glass, a transit in a car, a storing in an unheated stock etc.) (Müller, 2014; Müller & Valášek, 2014).

The results of performed experiments proved the essential influence of the storing management in the area of the adhesive bonding technology. The results suggest a necessity to keep the technologic discipline in the area of the storing temperature guaranteed by a producer.

From the results it is obvious that the packing type is essential for a transfer of surroundings temperature into the adhesive. From measurements performed by the contactless infra-thermometer Testo 845 it is evident that there is a huge difference among the surroundings temperature, the temperature of the adhesive and the temperature of mixed adhesive. Optimum storing temperatures were determined in the interval 15 to 30 °C (Müller, 2014).

The results of performed experiments proved the essential influence of the storing management (logistic) in the area of the adhesive bonding technology. The results suggest a necessity to keep the technologic discipline in the area of the storing temperature guaranteed by a producer (Müller & Valášek, 2014).

The adhesive A3T30 can be recommended in cases where the constant temperature (the laboratory one, 22 °C) is not secured owing to the practical application in the logistics area that means transit, storing etc. The adhesive LN7256 is suitable to use till maximum temperature 60 °C. Negative storing values not exceeding tested–20 °C do not decrease utility properties.

Investigated laboratory is used as a research and teaching purposes, therefore sanitary conditions for students and staff must be respected. The requirements of health and safety at work are summarized in Decree no. 361/2007 Coll., (Act No. 262/2006 Coll.). The rules work in the lab ranked according to the total average energy expenditure $M \leq 80$ W m^{-2}, class work I, therefore, the air temperature should be in winter 22 ± 1.5 °C if the expected thermal resistance of a clothing is 1.0 clo, and relative humidity of air from 30 to 70%. Natural ventilation is insufficient in this type of laboratory and therefore must be applied a mechanical ventilation 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 P 11 (diethylene). Exposure limit values for these substances are listed in Table 1.

Table 1. Chemical agents registered in Chemical Abstracts Services (CAS), Occupational Exposure Limits (OEL) and Maximum Exposure Limits (MEL)

Agent	CAS	OEL, mg m^{-3}	MEL, mg m^{-3}
Acetone	67-64-1	800	1,500
Benzyl alcohol	100-51-6	40	80
Bisphenol A	80-05-7	2	5
Diethylene triamin	111-40-0	4	8
Ethanol	64-17-5	1,000	3,000
Tetrachlor ethylene	127-18-4	250	750
Toluene	108-88-3	200	500

Dust that is release into the surrounding air during the preparation of samples corresponds to the material used for the adhesive bonding. Most often it is a metal, plastic or wood. According to the type of material, dust has specific characteristics to which respond the properties. According to the (Act No. 262/2006 Coll.), there can be dust with nonspecific effects (metals) or irritating effects (plastics and wood). For these types of dust there are prescribed OEL permissible exposure limits of total concentration. Occupational exposure limits are listed in the Table 2.

Table 2. Dust and Occupational Exposure Limits (OEL)

Dust	OEL, mg m^{-3}
Iron and iron alloys	10.0
Aluminum and its oxides	10.0
Wood (common species)	5.0
Phenol-formaldehyde resin	5.0
PVC	5.0
Polyethylene	5.0
Polypropylene	5.0
Polymeric materials	5.0
Polystyrene	5.0
Glass laminates	5.0

Referred Exposure Limits OEL and MEL valid for the Czech Republic may be in some cases slightly different (usually higher) from exposure limits valid in the EU or in other countries, however, the principles and solution of this research these small differences do not affect.

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 from three connected rooms are 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 the experimental work, mainly for adhesive bonding. The rooms have the following dimensions: total volume of room is O = 357 m^3 and inside maximum can be 26 persons. The ground plan of the laboratory is presented on the Fig. 1.

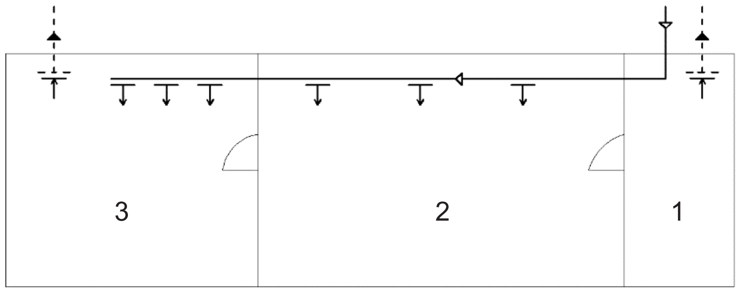

Figure 1. Ground plan of the laboratory, where: 1–storage, 2–teaching area, 3–experimental area.

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, there was measured by data loggers ZTH65 temperature and humidity with registration during the experiments. Parameters of ZTH65 are: temperature operative range -30–80 °C with accuracy ± 0.4 °C and operative range of relative humidity 5–95% with accuracy ± 2.5%.

The thermal comfort in the space was continuously measured by globe temperature (measured by globe thermometer FPA 805 GTS with operative range from -50 to +200 °C with accuracy ± 0.1 K and diameter of 0.15 m) together with temperature and humidity of surrounding air measured by sensor FH A646–21 including temperature sensor NTC type N with operative range from -30 to +100 °C with accuracy ± 0.1 K, and air humidity by 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 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 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. Measured dust inside the offices is not aggressive, it has properties as house dust, therefore, as a criterion for evaluation of the measured values was selected the limit level of outdoor dust, which is 0.050 mg m^{-3} (50 µg m^{-3}).

RESULTS AND DISCUSSION

Chemical agents or aerosol including dust should be captured and exhausted according to the technical possibilities at the source (Act No. 262/2006 Coll.). This is not possible in this laboratory due to the extent of work and technological activities. Therefore, it must be overall ventilation of the whole room space. There can be used different method for the air flow determination. The first methods are based on the knowledge of quantity of mass flow of the pollutants which are leaking into the ventilated space. The other methods are based on the empirical knowledge and information from standards (prescribed ventilation rates of fresh air per one person or prescribed air exchange of the volume of the room) (Chysky et al., 1993). These methods were used for calculation of the ventilation rate. The real airflows in inlets and outlets were measured as well.

Calculations of the air flow

Assuming steady conditions with a uniform distribution of pollutants in space the required volume air flow for ventilation V_c according to the equation (1).

$$V_c = \frac{M_p}{c_i - c_e} \tag{1}$$

where: V_c – required volume air flow for ventilation, m^3 h^{-1}; M_p – mass flow of produced pollutant, uniformly leaking into the space, kg h^{-1}; c_e – concentration of pollutant in inlet air, kg m^{-3}, (usually is $c_e = 0$); c_i – concentration of pollutant in outlet air, kg m^{-3}, (usually is OEL or MEL).

Due to the fact that the manufacturers do not provide the data on the release of harmful substances into the atmosphere, the mass flow values of produced pollutant M_p of several most important pollutants were measured experimentally in the laboratory. Determined productions M_p of harmful substances presented in the Table 3.

Table 3. Mass flow of produced pollutants

Agent	M_p, mg h^{-1}
Acetone	2,499.2
Toluene	1,005.6

According to (Act No. 262/2006 Coll.) must be 50 m^3 h^{-1} minimum amount of air entering the workplace for an employee performing a work classified to Class I. In extra load space by odours 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 the equation (2).

$$V_{min} = n_1 \cdot d \tag{2}$$

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

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 the equation (3). The results of airflow calculated according to all described methods are summarized in the Table 3. It is obvious that the results of airflow calculation based on the mass flow of produced pollutants inside the rooms are very small in comparison with the results of calculation according to the empirical methods. Therefore the suitable ventilation rate can be determined according the biggest calculated value from the Table 3 which is V_I is 1,607 m^3 h^{-1}.

Calculation of air flow according to the prescribed air exchange V_I:

$$V_I = I \cdot O \tag{3}$$

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

Table 4. Calculated values of air flows

-	$V_{cAcetone}$, $m^3\ h^{-1}$	$V_{cToluene}$, $m^3\ h^{-1}$	V_{min}, $m^3\ h^{-1}$	V_I, $m^3\ h^{-1}$
According equation	1	1	2	3
Airflow rate	3.12	5.03	1,300.00	1,607.41

The real airflow ventilation rates supplied to and discharged from the ventilated laboratory are the same. During the normal conditions when the pollution inside the room is not so intensive can be used I level of ventilation, approximately 720 $m^3\ h^{-1}$. The ventilation rate 1,440 $m^3\ h^{-1}$ (II level) is used if the pollution of air inside the laboratory is maximal, during intensive research work and teaching activity.

Results of measurements

The results of measurement of main microclimatic parameters in the laboratory are presented in the Table 5. The air temperature should be in winter 22 ± 1.5 °C for the 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 globe temperature is higher than the average air temperature which is caused by the radiation form the surrounding walls and mainly the ceiling which contents the heating pipelines of central heating systems. The positive influence of ventilation on the concentration of noxious gases is obvious from the decrease of CO_2 concentration in the Table 5 and Fig. 2.

Table 5. Average values and standard deviation of air external temperature t_e, external relative humidity RH_e, and temperature t_i, globe temperature t_g, relative humidity RH_i and CO_2 in the laboratory during the different levels of ventilation, without ventilation (0 level), standard ventilation (I level) maximal ventilation (II level)

Ventilation	t_e	RH_e	t_i	t_g	RH_i	CO_2
-	°C ± SD	% ± SD	°C ± SD	°C ± SD	% ± SD	% ± SD
0	2.06 ± 1.03	70.44 ± 3.95	20.93 ± 0.03	21.34 ± 0.02	34.18 ± 0.41	0.053 ± 0.003
I level	3.73 ± 0.62	63.30 ± 3.20	20.83 ± 0.14	21.15 ± 0.08	29.68 ± 1.44	0.038 ± 0.006
II level	5.36 ± 0.79	57.03 ± 2.38	21.28 ± 0.06	21.46 ± 0.09	26.60 ± 0.59	0.033 ± 0.000

SD –Standard deviation

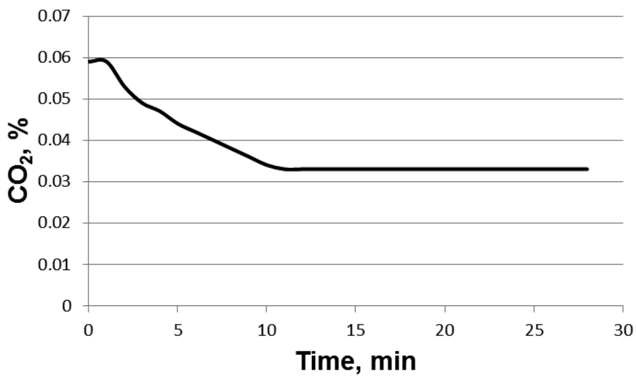

Figure 2. The course of CO_2 concentration in the laboratory with level I of ventilation capacity.

The resulting concentration 0.033% CO_2 corresponds according to our measurement to the concentration of CO_2 in outdoor air. By further or more intensive ventilation therefore cannot be achieved lower concentration of CO_2.

The dust concentration in the laboratory was very high. Principal results of dust measurement are summarized and presented in the Figs 3–5. The Fig. 3 presents results of measurement inside the laboratory without ventilation. The average concentration of total dust pollution was very high, nearly 0.2 mg m^{-3}. Prescribed occupational exposure limits OEL of total concentration for all types of dust according to the Table 2 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 m^{-3} (50 µg 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 (Figs 4 and 5), but the limit level 0.050 mg m^{-3} was exceeded in total concentration of dust and also of all fractions in both cases of ventilation levels.

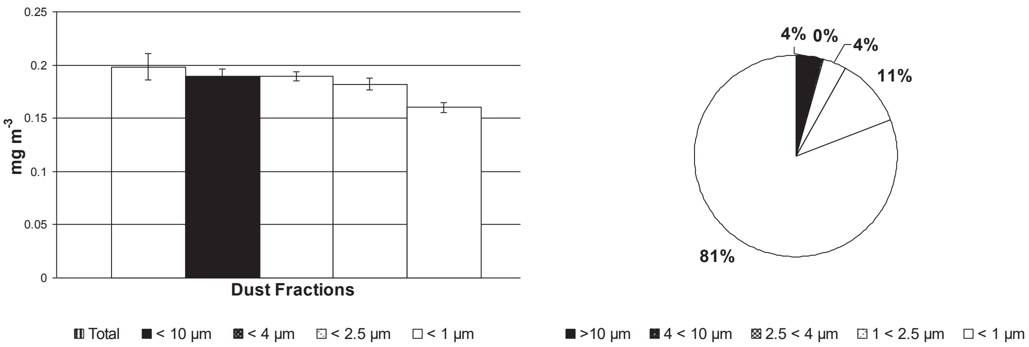

Figure 3. Concentrations and percentage of dust fractions inside the laboratory without ventilation.

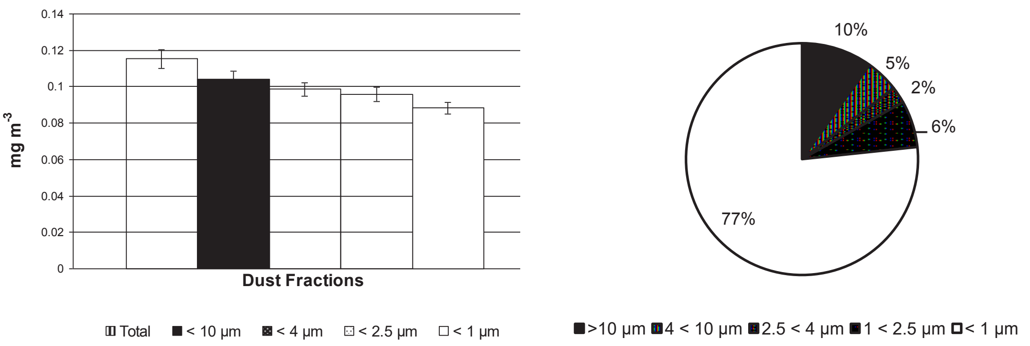

Figure 4. Concentrations and percentage of dust fractions inside the laboratory with ventilation level I.

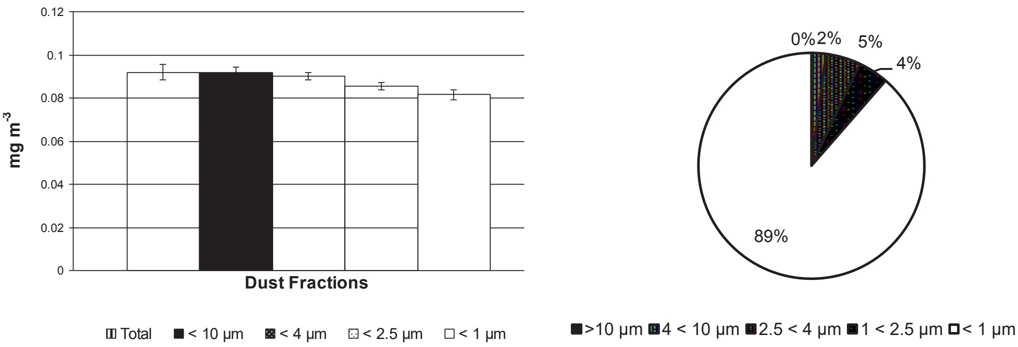

Figure 5. Concentrations and percentage of dust fractions inside the laboratory with ventilation level II.

The dust concentration decreased in all size of dust particles. Due to different particle dimensions and therefore different aerodynamic properties, more intensive ventilation with higher velocity of air streams the percentage of each size particles has been changed in the measured total dust concentrations. A higher percentage of the smallest particles PM_1 results from their greater dispersion in the space, but the total concentration PM_1 during more intensive ventilation is also smaller.

CONCLUSIONS

The results of calculations of ventilation parameters and measurements in the laboratory showed that:

- the capacity of ventilation can be determined according to the prescribed ventilation rate per one persons and number of students or workers inside;
- the function of ventilation improve the inside microclimate from the point of view concentration of CO_2 and dust pollution;
- the biggest percentage of dust particles in this type of laboratory are small size particles PM_1;
- thermal state of indoor microclimate is positively influenced by the thermal radiation from the surrounding walls.

ACKNOWLEDGEMENTS. Supported by Internal grant agency of Faculty of Engineering, Czech University of Life Sciences in Prague no: 2015:31170/1312/3114 and no: 2015:31140/1312/3106

REFERENCES

Act No. 262/2006 Coll. Government Regulation No. 361/2007 Coll. Laying down the conditions for the protection of health at work. Changes: 9/2013 Coll. 48 pp. (in Czech).

Cidlina, J., Müller, M. & Valášek, P. 2014. Evaluation of Adhesive Bond Strength Depending on Degradation Type and Time. *Manufacturing Technology* **14**(1), 8–12.

Court, R., Sutcliffe, M. & Tavakoli, S. 2001. Ageing of adhesively bonded joints–fracture and failure analysis using video imaging techniques. *International Journal of Adhesion & Adhesives* **21(**6), 455–463.

Chysky, J. Drkal, F., Hemzal, K., Kubíček, L. & Nový, R 1993. *Ventilation and Air Conditioning*. BOLIT, Brno, 560 pp. (in Czech).

Kic, P., Kalvoda, T. & Zavadil, V. 2007. Energy savings by heat recovery in ventilation. *Conference Proceedings–3rd International Conference on Trends in Agricultural Engineering.* CULS, Prague, 215–218.

Müller, M. 2014. Influence of adhesives storing temperature on adhesive bond strength. *Manufacturing Technology* **14**(1), 71–75.

Müller, M. 2013. Research of liquid contaminants influence on adhesive bond strength applied in agricultural machine construction, *Agronomy Research* **11(**1), 147–154.

Müller, M. & Valášek, P. 2012. Degradation medium of agrokomplex–adhesive bonded joints interaction. *Research in Agricultural Engineering* **58(**3), 83–91.

Müller, M. & Valášek, P. 2014. The logistics aspects influencing the resultant strength of adhesives at practical application. *Agronomy Research* **12**(1), 285–290.

Zajicek, M. & Kic, P. 2014. Heating of large agricultural and industrial buildings. *Agronomy Research* **12**(1), 237–244.