

# Optimization of environmental maintenance system used in a refuge chamber

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**Abstract** Mine refuge chambers are used to shield miners who fail to escape from the mine when incidents occur. Environment maintaining system plays a key role in stabilizing thermal environment of a mine refuge chamber against heat emitted from metabolism and transferred from outside. The safety and comfort of refugees are closely related to the environment maintaining system design. In order to improve the comfort of refugees, optimization on the environment maintaining system has been done based on the previous work. To evaluate the environment of the chamber, eight volunteers were involved into the experiment. Under close observation and safety protection, they lived in a heat-isolated test chamber for 106 hours. The volunteers were asked to maintain low level of activities to simulate refugees' situation. It shows that the environment maintaining system worked well and the temperature, relative humidity and emitted harmful air content such as CO<sub>2</sub> and CO were all kept in the safety level, and no discomfort was felt by volunteers at all.

**Keywords** Environment maintaining system · Mine refuge chamber · Temperature · Relative humidity · CO<sub>2</sub> concentration · CO concentration

## 1 Introduction

Mine refuge chambers are used to shield miners who fail to escape from the mine when incidents occur. They should provide breathable air, food, water and a safe environment, which is essential to the refugees.

Mine refuge chamber would be heated and humid due to internal refugees and external underground situation. High levels of heat and humidity could cause sweating, paleness, cramps, tiredness, weakness, dizziness, headache, nausea or vomiting, and fainting. An environment maintaining

system includes a refrigerator, a pressure balance system and an air cleaning subsystem. The refrigerator mentioned in previous work is used to control temperature and humidity in the chamber. The pressure balance system is used to keep the internal pressure in a reasonable range. The air cleaning subsystem, also located in the refrigerator, is used to absorb CO<sub>2</sub> and CO in the air recycling (Yang and Yang 2013).

The temperature, relative humidity and the concentration of CO<sub>2</sub> and CO are important factors that affect the comfort and safety of the refugees

There were a large number of studies about the thermal comfort in offices and work buildings. Memon assessed the thermal comfort within the classroom of a university in subtropical of Pakistan and found that more than 80 % of people were satisfied at an effective temperature of 32.5 °C (Memon et al. 2008). Sander ter Mors et al. investigated the thermal comfort and thermal comfort parameters for children in primary school classrooms. The questionnaires had been applied to obtain the actual thermal sensation and clothing insulation in the morning and afternoon of regular

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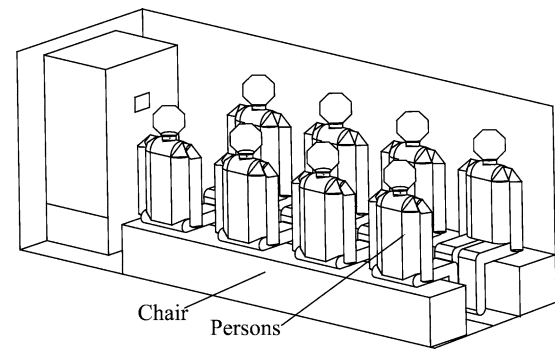
school days (Mors et al. 2011). Noh et al. studied thermal comfort and indoor air quality in lecture room (Noh et al. 2007). Muhi and Butala studied the influence of thermal environment and air quality level on the employees in the mechanical ventilated administrative offices (Muhi and Butala 2004). An examination of thermal comfort in a hospital had been conducted (Pourshaghaghay and Omidvari 2012). Abbritti et al. estimated the value of PMV in sick buildings (Abbritti et al. 1992). Sabrina et al. assessed indoor environment quality for hypermarket workers and found that data collected at fixed point locations showed only minor (and predictable) biases due to expectation and to transition through different thermal environments (Sabrina et al. 2012). Jan et al. made an evaluation of the optimal temperature in each cabin of the Korean maritime patrol vessels and found that the optimum temperature was 23 °C in the wheelhouse and 29 °C in the accommodation (Jan et al. 2007).

All the papers mentioned above focused on the environment of the ordinary buildings. The mine refuge chamber is narrow in space and works in incidents situation. In result of these features, internal environment condition and air quality would be different from previous studies. Jia et al. investigated the refrigerating characteristics of ice melting enclosed in a cube capsule in coal mine refuge chamber (Jia et al. 2015). Jia et al. studied on purification characteristic of CO<sub>2</sub> and CO within closed environment of coal mine refuge chamber by mean of the simulation device (Jia et al. 2014). In this paper, the performance of the environment maintaining system is examined.

## 2 Experiment description

In the experiment, a full-size heat isolated chamber was built, and eight volunteers lived in the chamber for 106 hours under close observation and safety protection. Their age ranges from 18 to 35, and they had the same wearing. During the experiment, they could only consume food and water prepared in the chamber and the door of the chamber was kept closed. If any discomfort was felt or the volunteers were in danger, the door could be opened from both inside and outside. The volunteers had breakfast regularly at 8:00 am, lunch at 12:00 am and supper at 5:00 pm. In most of duration, they were asked to maintain low level of activities. It is shown in Fig. 1 that the volunteers were sitting in the chamber.

Figure 2 is the photo of the refrigerator and air cleaning subsystem. Figure 2a is the previous one and Fig. 2b is the present design. The present one is a compacter design and the air flow distributes more non-uniformly. The refrigerators are open cycle because the compressor should not be used in a coal



**Fig. 1** Persons sitting in the chamber

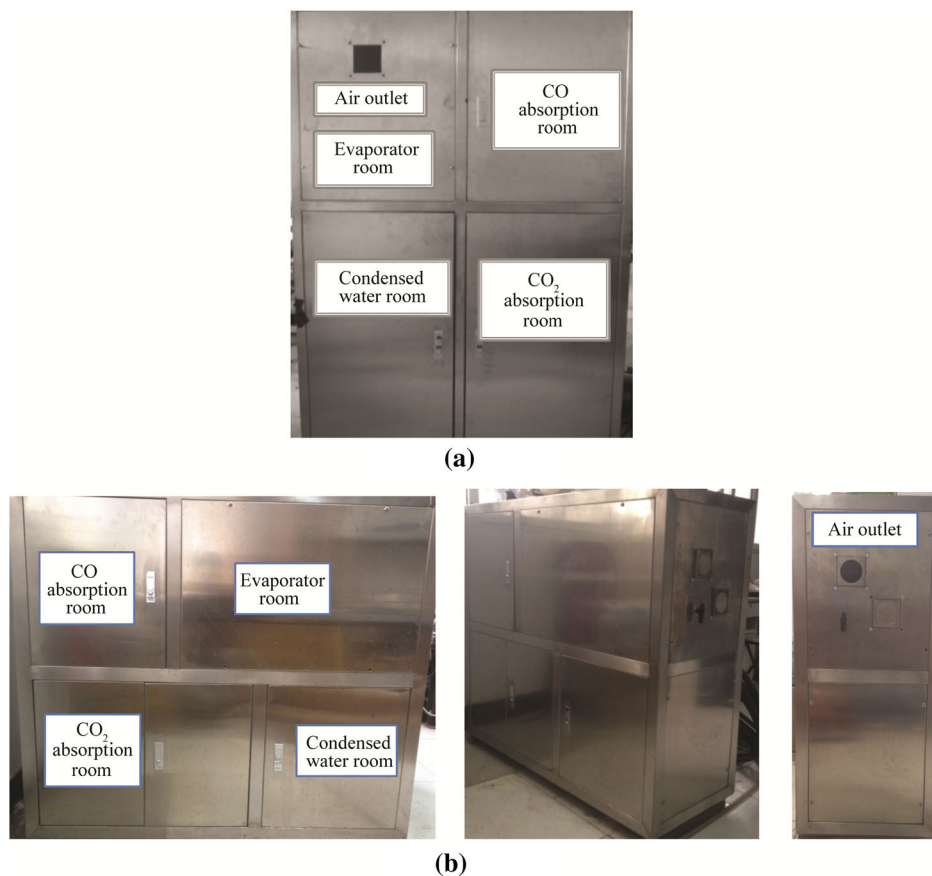
mine. On the one hand, in most situations the electric power supply breakdown will occur at an accident, and the refrigerator will fail to run. On the other hand, the compressor is located outside of the refuge chamber, and could be damaged by gas explosions that often occur in underground coal mines (Fang et al. 2012; Zhao and Qian 2012; Zhao et al. 2012).

Both of the refrigerators include four rooms. The air outlet is aligned differently in position to the four rooms. Once the air in the chamber goes into the cabinet, it will travel in such a sequence: Firstly, air with ambient temperature is inhaled into the cabinet at the bottom, and then goes through the condensed water room. After reducing humidity air goes through the CO<sub>2</sub> absorption room and the CO absorption room in sequence, where CO<sub>2</sub> and CO is absorbed. Then, the air goes through evaporator and is cooled down as a result. Finally, low temperature and breathable air is blown out from the cabinet into the chamber.

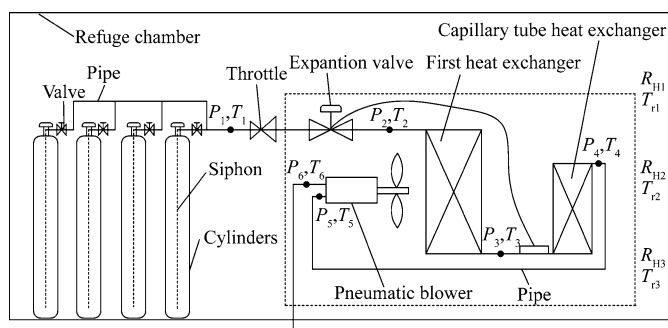
The personnel activity was observed by a camera in real time, and the experiment data of temperature, relative humidity, CO<sub>2</sub> concentration and CO concentration in the chamber were recorded by the computer.

Three thermometers ( $T_{r1}$ ,  $T_{r2}$  and  $T_{r3}$ ) were arranged in the chamber evenly in heights, see Fig. 3. The relative humidity sensors, CO<sub>2</sub> concentration sensors, CO concentration sensors, O<sub>2</sub> concentration sensors and gauge pressure sensors were at the same location of the three thermometers. The dates were recorded every 30 min. The dates in the follow figs were measured values by the sensors.

All the sensors used in the experiment were calibrated. The temperature was measured by pt100 thermometers with an accuracy of  $\pm 0.1$  °C, and the corresponding relative humidity is measured by JWSK-6 with accuracy of  $\pm 0.5$  °C ( $-20$  to  $60$  °C),  $\pm 3$  %RH ( $5$  %RH– $95$  %RH) made by a corporation named Collhigh in China. The pressure in the experiment is measured by MEAS pressure sensors calibrated with a standard pressure source with accuracy of  $\pm 0.25$  % BSL, max(combined linearity, hysteresis & repeatability). The CO concentration, CO<sub>2</sub> concentration and O<sub>2</sub> concentration were measured by sensors with accuracy of  $\pm 2$  %,  $\pm 0.1$  % and  $\pm 3$  %, respectively.



**Fig. 2** Refrigerator and air cleaning subsystem. **a** The previous, **b** the present



**Fig. 3** Arrangement of the sensors

### 3 Experimental results and discussions

#### 3.1 Temperature and relative humidity in the chamber

Figures 4 and 5 are the temperature and relative humidity in the chamber. Internal temperature increased sharply after volunteers' entering. The heat from volunteers' metabolism warmed internal air up to 30 °C. Because they were in exciting or anxious mood, depending on their different psychological status, the amount of diffused heat

was very large at this stage. After they calmed down gradually, the temperature decreased to an ordinary level and varied via time. Normally, the temperature ranged between 25 and 28 °C and the relative humidity ranged between 50 % and 70 %. When they had dinner, the temperature would increase to the maximum of 30 °C, while the relative humidity increases to 75 %. On contract, the temperature would drop down to the minimum of 23 °C with a relative humidity of 45 % when they were sleeping. It is shown that level of personnel's activity impact internal temperature and relative humidity greatly in such a narrow

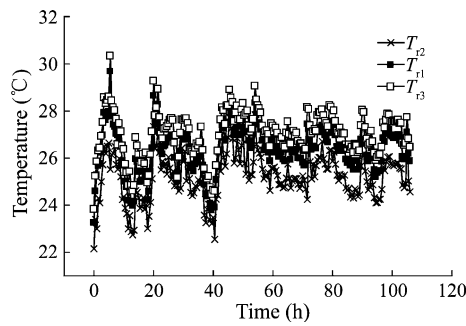


Fig. 4 Temperature varies with time in the chamber

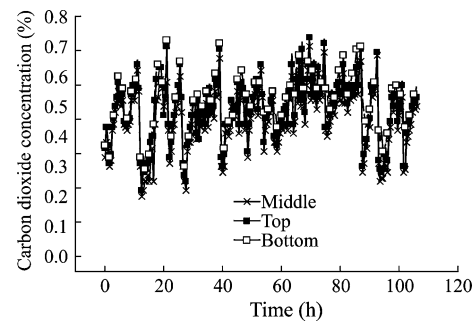


Fig. 6 CO<sub>2</sub> concentration varies with time in the chamber

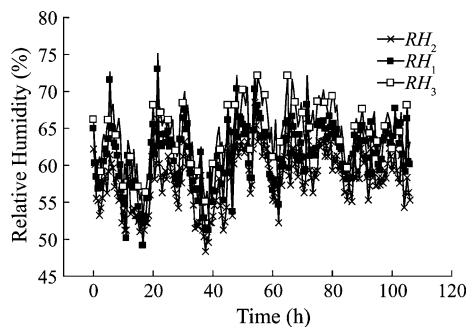


Fig. 5 Relative humidity varies with time in the chamber

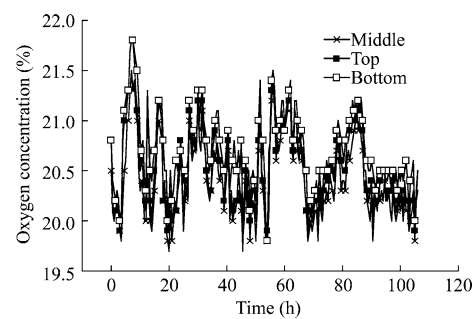


Fig. 7 O<sub>2</sub> concentration varies with time in the chamber

space. Position of  $Tr_2$  was located towards the cold air flow, which resulted a low reading than  $Tr_1$  and  $Tr_3$ .

### 3.2 CO<sub>2</sub> and O<sub>2</sub> concentration in the chamber

The concentration of CO<sub>2</sub> and O<sub>2</sub> are 1 % and 21 % respectively in atmosphere. Regarding the complex situation in the refuge chamber, the concentration might change, but should stay in breathable level. So the extra CO<sub>2</sub> should be absorbed by the air cleaning system. Figure 6 illustrates the CO<sub>2</sub> concentration in the 106 h. The concentration varied between 0.2 % and 0.7 % and remained stable, nearly 0.5 %, most of the time. This means the absorption capability is enough for 8 personnel. In this result, it also could be seen that the concentration was lower in the middle than the other two positions due to a better convection situation.

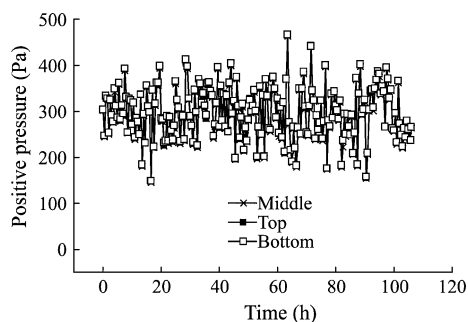
The O<sub>2</sub> is supplied by the O<sub>2</sub> cylinders placed in the chamber before the experiment. The flow rate of the O<sub>2</sub> is controlled by a throttle. Figure 7 is the concentration of O<sub>2</sub> in the chamber. It ranged from 19.5 % to 22 %. From the data above, it could be seen that the air in the closed chamber has almost the same content as the atmosphere, which ensures the personnel's safety.

### 3.3 Pressure in the chamber

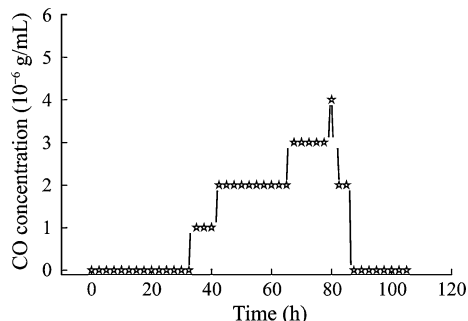
Tinnitus, chest distress and poor breath might happen when persons are living in an environment with too high or too low pressure. The pressure balance system is designed to maintain a suitable pressure in the chamber by supplying and relieving air when the pressure is below -200 Pa and over 600 Pa. Figure 8 shows the gauge pressure in the chamber. It could be seen that the gauge pressure varied round 300 Pa in the range of 150–450 Pa. The sensors at the three positions had almost the same reading. Due to this pressure balance system, no discomfort was felt during the experiment.

### 3.4 CO concentration in the chamber

High concentration of CO might lead to CO poisoning. CO is rarely produced in human's metabolism, in case of incidental accumulation, CO absorbing function is designed to active automatically according to CO concentration. Figure 9 is the CO concentration during the experiment. The concentration of the CO was zero in the first 30 h and CO absorbing function was off. When small amounts of CO was produced by metabolism and accumulated up to  $4 \times 10^{-6}$  g/mL at maximum, the CO absorbing function was triggered on automatically. After



**Fig. 8** Gauge pressure varies with time in the chamber



**Fig. 9** CO concentration varies with time in the chamber

30 min, CO concentration reduced. During this period the volunteers did not feel uncomfortable at all.

In summary, the environment maintaining system functions as follow: air in the chamber is inhaled into the cabinet, the pollution in the air is absorbed and the air is cleaned and cooled down in the refrigerator, then cool and fresh air is blown out. The environment maintaining system provides a fundamental environment for human's living. According to the experiment above, all the functionality of the system ran well and no discomfort was felt in the duration of 106 hours. This means the system has the capability to provide a good environment for life maintenance in case of incidents. To improve personnel's comfort, the flow around the human body would be further analyzed.

## 4 Conclusions

The environment maintaining system was optimized and tested when eight volunteers living in. The experiment results showed the conclusions as follow:

- (1) The system could control the temperature between 25 and 28 °C and the relative humidity was between 50 % and 70 %, which were the comfortable range for human being.
- (2) The CO<sub>2</sub> concentration varied between 0.2 % and 0.7 % and stayed nearly 0.5 %, which was the same as the air content and was safe.

- (3) The O<sub>2</sub> concentration ranged from 19.5 % to 22 % and was suitable for breathing.
- (4) The gauge pressure was controlled in the range of 150 to 450 Pa.

All the parameters were within the safety range, and no discomfort was felt. This meant the optimizing of the environmental maintaining system was reasonable and was useful for the design of the chamber.

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