ABSTRACT
To analyze the relation between indoor environment, human and productivity, a field survey was carried out in a natural ventilation (NV) building in Zhenjiang. The results show that productivity (103.2%) does not the highest in the neutral or comfort state. The highest productivity occurs when thermal sensation vote is slightly cool (105.1%). The productivity in slightly warm state is 104.5% which is also higher than in neutral state. More than 60% subjects reported that increasing outdoor air could make them more comfortable. The proportion of choosing indoor temperature and humidity was less than 12%. People in good air quality environment could easily get high productivity when the thermal environment is acceptable. Compared with other factors, keeping good indoor air quality may be the best way to maintain the higher productivity in the factories in this survey.

INDEX TERMS
Productivity, Thermal sensation, Indoor air quality, Natural ventilation

INTRODUCTION
Increased attention has been paid to the relationship between the work environment and productivity since the 1990s. Laboratory and field studies show that the physical and chemical factors in the work environment may have a notable impact on the health and performance of the occupants, and consequently on productivity (Clements and Kaluarachchi 1999, Wargocki et al. 2000, Wargocki et al. 2002, Ye et al. 2003, Ye and Lian 2005). Because the average employee spends up to 95% of the time indoors, the indoor environment can have a direct effect on health, comfort, and productivity. Lack or poor indoor environment has a direct on users’ productivity and an indirect effect to actual buildings’ energy efficiency (Kolokotsa 2001).

There are numerous factors that can make up a working environment. This relationship, however, has been insufficiently explored. The elusive relationship between thermal environment and productivity has attracted the attention of researchers for many years. Nevertheless, the factors of the environment are usually considered separately. Some attempt at integration of effects can be made, but, there is insufficient objective knowledge to allow an accurate quantification (Parsons 2000).

In this paper, a major part of the research is focused on improving the understanding of the interaction between productivity, human and the indoor environment. The discussion is main confined to the factors of thermal sensation, air quality. Moreover, other non-environmental factors will also briefly be considered.

METHODS AND BACKGROUND DESCRIPTIONS
To analyze the relation between indoor environment, human and productivity, a field survey was carried out in a NV building in Zhenjiang. Zhenjiang city, locates in the east of China, is famous for its light industry. Fig.1 shows the monthly average air temperatures for a period of 10 years. The mean temperature during each month ranges from approximately 2.5°C in January to 27.1°C in July.

In this study, air temperature, mean radiation temperature, air velocity and relative humidity were measured (Ye et al. 2004). The thermal response of subjects was measured by asking them for a ‘comfort vote’ on a descriptive scale the same as the ASHRAE scale (ASHRAE 1993).
RESULTS AND DISCUSSIONS
Fig. 2 shows the relationship between thermal sensation and operative temperature. By using the linear regressed models to find the relationship between thermal sensation and indoor operative temperature for the NV building, the neutral temperature was found that was 18.3°C in winter and 19.8°C in autumn.

Fig. 3 shows that thermal sensation or temperature has an effect on the productivity. A subject’s everyday productivity in this study is calculated by Equation (1) and (2).

\[ N_a = \frac{1}{n} \sum_{d=1}^{n} N_d \]  
\[ P_d = \frac{N_d}{N_a} \times 100\% \]

Where, \( N_a \) is the average quantity of a subject’s piece-work; \( N_d \) is the quantity of a subject’s day piece-work; \( n \) is the number of investigation of a subject; \( P_d \) is day productivity, %.

When temperature was either too high or too low, error rates and accident rates increase and the productivity is lowered. From the regressive result, the highest productivity reaches at 104.1% when indoor temperature is 25.4°C, which is similar to that in the call centre (25°C) (Niemelä et al. 2002). In this survey, thermal comfort level has an effect on productivity in factory, and there are sufficient materials to assure most people that it is difficult to perform work effectively when temperature is too hot or too cold. From Fig. 3, the relationship between productivity and thermal sensation can be concluded, the regressed equation is

\[ y = -1.075x^2 + 10.11x + 81.12 \]

Where, \( y \) is productivity and \( x \) is thermal sensation.
Personal experience is sufficient to convince most people that it is difficult to study or perform work effectively when it is even slightly too hot or too cold. However, the productivity does not reach the highest when the occupant is in the neutral (103.2%) or comfort state, as shown in Fig. 3. The highest productivity occurs when thermal sensation vote of occupants is slightly cool (105.1%). Productivity of mental work is the lowest in slightly warm environments which may have soporific effects. However, manual work is different. The productivity in slightly warm state is 104.5%, which is higher than in neutral state. Wyon also points out in a review article, comfort or neutral does not always lead to the highest performance outcomes in experimental research (Wyon 1996). In factories, lots of work is manipulated by occupants’ fingers or hands, and cold environment has great influence on them than hot environment does. Fig. 3 shows that the productivity in cold (92.0%) or cool (92.6%) environment is lower than that in hot (98.2%) environment. With excess heat or cold, workers may feel very uncomfortable, and their efficiency drops. In a cold environment the veins are constricted, reducing the thermal conductivity of the tissue layer so that the skin cools. The dexterity and activity of their fingers or hands will decrease, which will influence productivity. However, in a warm or hot environment, a copious flow of blood is allowed through these vessels, so as to maintain its temperature excess over the surroundings. It does not decrease the dexterity and activity of the fingers greatly. That is the reason why productivity in cold environment is lower than that in hot environment in factories.

Many factors have the potential to interrupt work progress and to influence workers’ productivity. One of them is indoor air quality that causes work to progress at different rates. In the survey, the majority of the respondents consider the air quality levels in their building to be common and good; 78.13% subjects thought it common or good and less than 5% of the respondents rated the air quality levels to be unacceptable. From the Fig. 4, we can know that air quality has effect on productivity directly. Good air quality induces higher productivity (107.9%) and poor air quality brings lower productivity (95.6%). The relationship between productivity and air quality is linearity.

Poor air quality can have a significant negative effect on the employee’s health and productivity. Some experiments the prevalent belief among indoor environment professionals was that while poor indoor air quality might reduce productivity by affecting health and thus absenteeism, there were no direct effects on productivity (Fisk and Rosenfeld 1997). The performance of office work may increase by 5% when the air quality is improved to a higher
level from a mediocre level often found in practice (Wargocki et al. 2002). Studies show that productivity is higher in buildings in which occupants’ satisfaction and retention are increased, and there is a reduction of the number of sick days taken by occupants (Mohamed and Srinavin 2002). There are some indications that good air quality environment improves occupants’ work performance, work commitment and morale, with other positive implications for improving overall productivity. Poor indoor air quality might reduce productivity by affecting comfort sensation, mental health and thus absenteeism.

Although most of the attention related to productivity focuses on thermal factors and air quality, emotional state and workday are also important contributors to productivity. Fig.5 and Fig.6 show emotional state vote and workday statistic analysis in the NV building. Fig.5 indicates the relationship between emotional state and productivity is obvious. Comparison with 92.8% in bad emotional state, the mean productivity is 107.1% when occupants vote that they are in good emotional state. The difference reaches 14.3%. Since low morale generally translates into reduced productivity, it is clearly important for every company to make the effort to find ways to boost morale.

The relationship between workday and productivity is not linear. Productivity decreases from Monday to Thursday, but it increases on Friday. On Monday, the mean productivity reaches the highest (108.4%) and the lowest on Thursday (97.5%). People are vigorous in Monday after two days rest (Saturday and Sunday), so the productivity is high. On Friday, there is an expectation or motivation of day-off to occupants, so the productivity increases.

CONCLUSIONS
A field survey was carried out in a factory to investigate the relationship between occupants’ productivity and thermal environment. The data presented above shows that slight cool temperature and good air quality conditions in the building are more likely to have active or positive effects on people’s productivity during work. Neutral or comfortable environment does not always lead to the highest productivity. The cooler or warmer environment may enhance productivity than in a neutral comfortable environment. People in good air quality environment could have higher productivity. Compared with other factors, increasing air quality is the optimal method to improve or maintain higher productivity in a factory.
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REFERENCES