Window opening behavior and resultant thermal and air quality environment in elementary school classrooms

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ABSTRACT

A study was performed in 6 elementary schools in Japan, and measurements were made on temperature in classrooms and corridors, outdoor temperature, CO_2 concentration and closing or opening of windows and doors. As a result, it was found that when cooling or heating systems were not operated at room temperature of 20-30^oC, there were relatively high variations in the opening and closing conditions of windows and doors, and it was supposed that the opening conditions were being positively adjusted to improve indoor thermal environment. Also, when outdoor temperature was 30^oC or lower, indoor and outdoor temperature was within 80% tolerance limit of the adaptive model in most cases. There were the cases where CO_2 concentration exceeded the level of 5000 ppm during lesson hours if windows were completely closed when cooling or heating systems were operated. The results of the study suggest that excessive increase of indoor CO_2 concentration level may be avoided through suppression of the influence on indoor thermal environment by opening windows and doors on corridor side.

1. INTRODUCTION

Heating systems have been generally used in winter season in public elementary schools in Japan, but air-conditioning systems for cooling have not been propagated widely. In summer season, indoor environment has been mostly controlled through natural ventilation by opening windows, and summer vacation is normally scheduled in midsummer. In recent years, however, air-conditioning systems for cooling have been rapidly propagated in these schools because there is extreme temperature rise due to heat-island phenomenon in urban areas and because school pupils are now rather accustomed to air-conditioned environment through the experiences at their own homes.

Table 1. Outlines of object schools and measurement periods.

school	corridor type	measurement period	remarks
A	side corridor	6 Dec' 04 ~ 9 Dec' 04 18 Nov' 06 ~ 24 Nov' 06	
B	side corridor	29 Nov' 04 ~ 2 Dec' 04, 28 Nov' 06 ~ 1 Dec' 06	
C	side corridor	13 Dec' 04 ~ 17 Dec' 04, 4 Jul' 06 ~ 7 Jul' 06, 5 Dec' 06 ~ 8 Dec' 06	Fans installed only on top floor classrooms.
D	middle corridor	26 Sep' 06 ~ 30 Sep' 06, 26 Nov' 06 ~ 30 Nov' 06	Cooling systems installed when setting up classes for handicapped.
E	middle corridor	7 Oct 06 ~ 14 Oct 06, 2 Dec' 06 ~ 7 Dec' 06	Cooling systems installed to avoid noise from an adjacent trunk line.
F	side corridor	10 Jul' 06 ~ 14 Jul' 06, 15 Sep' 06 ~ 22 Sep' 06, 21 Nov' 06 ~ 27 Nov' 06, 11 Dec' 06 ~ 14 Dec' 06	Only temperature measured on July and September. Fans installed in all classrooms.

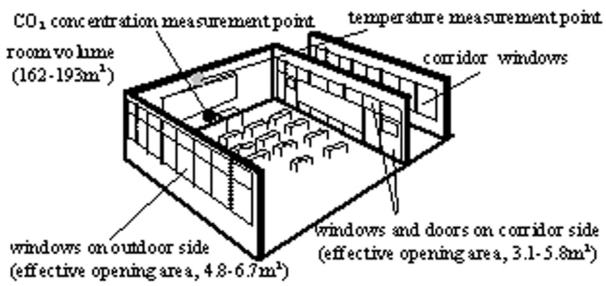

Figure 1. Configuration of classroom and measurement points.

The propagation of cooling systems in these schools may be affirmatively evaluated because the productivity may be improved with more comfortable indoor thermal environment, while it is not possible to neglect negative effects, such as the aggravation of heat-island phenomenon caused by the release of exhaust heat, the influence on physical condition of school children when they frequently move in and out between the air-conditioned classrooms and the outdoor space, and when exposed to poor air quality environment due to continuous closing of classrooms.

In this respect, we performed long-term measurements on the data including temperature, CO_2 concentration and opening and closing conditions of windows and doors in 6 elementary schools, which are located in the regions under warm climatic conditions with or without air-conditioning systems. By analyzing the experimental results, we aimed to have the findings useful for adequate operation of cooling or heating systems, and to determine recommendable procedure for opening and closing of windows and doors in classrooms.

2. OUTLINE OF MEASUREMENT

General outlines of the objects under study are summarized in Table 1. The study was performed on schools of A to F, and measurements were made on 2 – 8 ordinary type classrooms in each school. The table shows general features of school buildings, the period of measurement, and whether air-conditioning systems are installed or not. Configuration of the classroom under study, arrangement of openings, and positions of the measuring points are shown in Fig. 1.

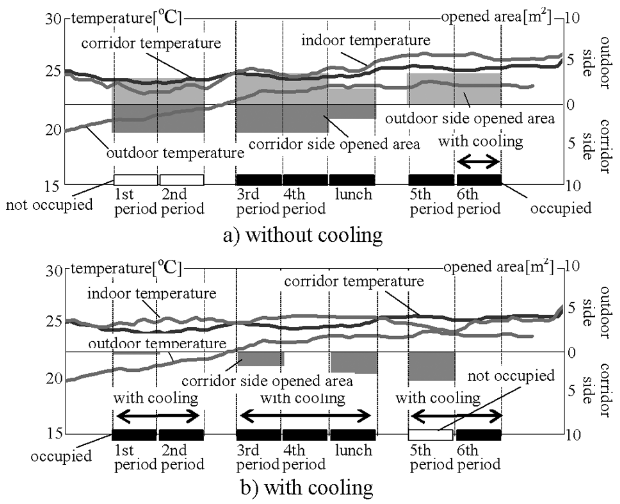

Figure 2. Temperature and opening conditions of windows and doors in summer season. (school D, 30 sep)

For the measurement of temperature and CO_2 concentration, compact type data logger and passive type CO_2 concentration measuring instrument were installed. To determine opening conditions of windows and doors and numbers of pupils in classrooms, investigation staffs visited classrooms during lesson hours, and the data were collected by visual inspection. For each season, data for one week were collected. Also, by using exhaled CO_2 from pupils as a tracer gas, ventilation rate was calculated applying the average of the inverse concentration method (Etheridge & Sandberg, 1996 and ISO12569, 2000) from the results of CO_2 concentration measurement.

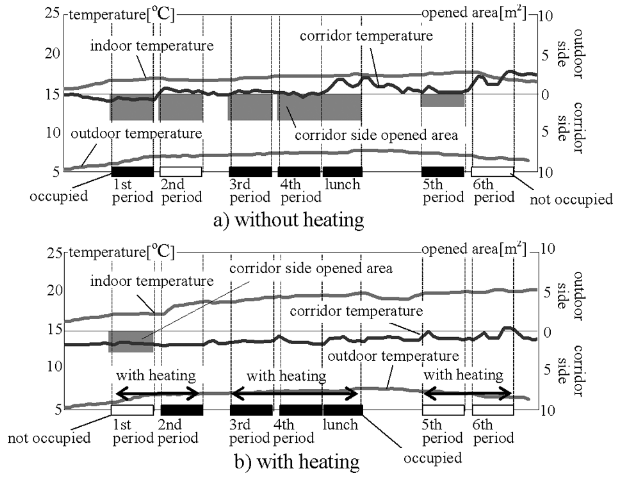

Figure 3. Temperature and opening conditions of windows and doors in winter season. (school F, 12 Dec)

3. THERMAL ENVIRONMENT

3.1 Temperature and opened area of windows and doors

Fig. 2 and Fig. 3 represent temperature in each classroom, in corridor and outdoor temperature, closing and opening conditions of windows and doors, number of pupils in classroom, and operating conditions of cooling or heating systems respectively. As shown in Fig. 2, during summer season when cooling systems are not used, windows and doors are opened in the morning and these are kept to be opened all the day. Windows are almost totally opened except the windows at upper positions, which are normally difficult to reach. When cooling systems are used, windows and doors are completely closed all day long to avoid the outflow of the cooled air in the room - probably by the instructions from the teachers. The temperature in classrooms is considerably closer to the temperature at corridors.

On the other hand in winter season, the windows on outdoor side are not opened irrespective of the use of heating system in most cases to avoid the inflow of the cold external air, and only the windows or doors on corridor side are opened. Even when the windows or doors on corridor side may be opened, the temperature in the classroom is not greatly decreased because the temperature at corridor is considerably higher that the outside.

3.2 Relationship between temperature and opened area

Fig. 4 shows average temperature in classrooms and corridors and outdoor temperature in each month when cooling or heating systems are not used during the period of measurement. Room temperature is higher than outdoor temperature, and the temperature at corridor is somewhere at the middle between the room and the outdoor temperature.

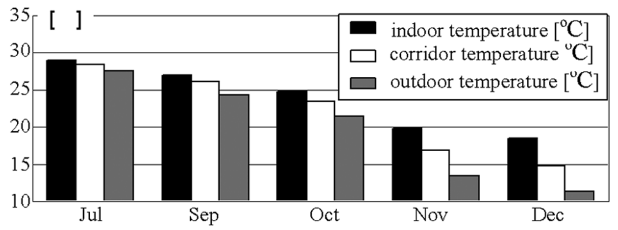

Figure 4. Average indoor temperature in classrooms and corridors and outdoor temperature in each month without heating or cooling.

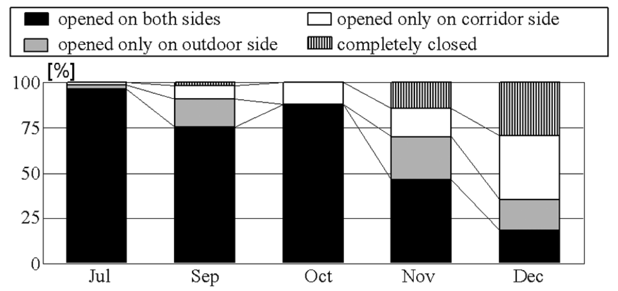

Figure 5. Opening conditions of windows and doors in each month without heating or cooling.

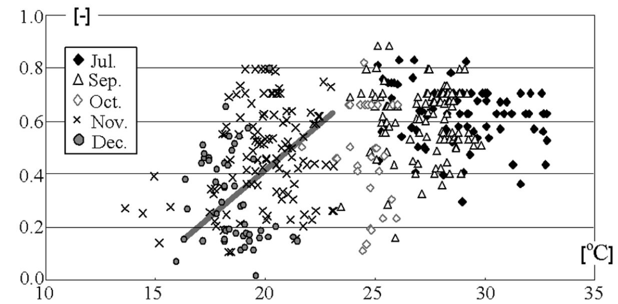

Figure 6. Relation between opening ratio of windows and doors and indoor temperature. (opened on both side)

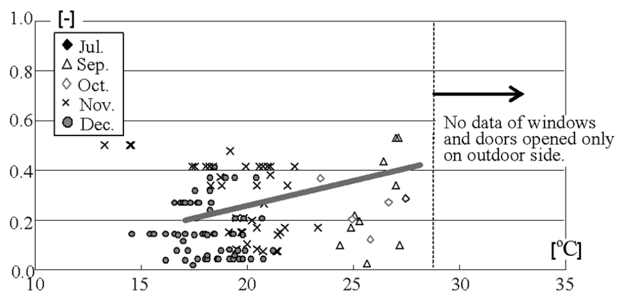

Figure 7. Relation between opening ratio of windows and doors and indoor temperature. (opened only on outdoor side)

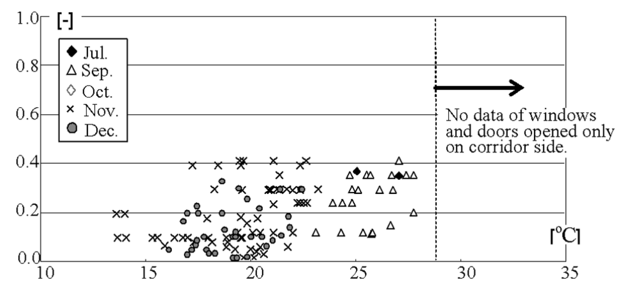

Figure 8. Relation between opening ratio of windows and doors and indoor temperature. (opened only on corridor side)

The opening conditions of windows and doors when cooling or heating systems are not used are shown for each month in Fig. 5. In this figure, the conditions are divided into 4 types, i.e. opened only on outdoor side, opened only on corridor side, opened on both sides, and completely closed, and the frequencies are shown under each of these conditions. During the period from July to October under relatively warm conditions, the openings on both sides, i.e. outdoor side and corridor side, are opened. This may be due to the efforts to improve indoor thermal environment by promoting ventilation.

During cold season in November and December, the frequencies to open windows and doors on both sides are decreased. In December, the frequency to open only either outdoor side or corridor side is about 50%. This may be attributed to the fact that the opening of windows on outdoor side is decreased and the frequency to open the windows or doors on corridor side is increased to avoid the aggravation of thermal environment caused by direct inflow of outdoor air into rooms. In Fig. 6 to Fig. 8, the relationship between opening ratio of windows and doors to the total opening area and indoor temperature is shown when cooling or heating systems are not used. The conditions were divided to two cases: the case where windows and doors are opened on both outdoor side and corridor side, and the case where only windows and doors of either outdoor side or corridor side are opened. In the figure, the data are shown for each month when measurement was made.

When windows and doors are opened on both sides, the variation of the opening ratio is relatively low when room temperature is 30 °C or higher. But, when room temperature is lower than 30 °C, the variation is higher. This may suggest that indoor thermal environment is controlled by the opening of windows. In November and December, the areas of openings are also decreased with the decrease of room temperature, and this reveals that efforts are made to keep room temperature comfortable. Even when room temperature may be on the same level, the opening ratio is higher in November than in December. As shown in Fig. 4, there is no large difference in outdoor temperature between November and December, and there may be influence of adaptation in the efforts to open the windows.

When attention is given on the case where only the windows on outdoor side are opened, the opening ratio is decreased as the decrease of room temperature. On the other hand, when windows are opened only on corridor side, the opening ratio in December is reduced to low level, but high variation is found as a whole, and this may be caused by the conveniences and the situations in each classroom such as moving of pupils in and out before and after the lesson hours rather than due to the intentional opening of windows to keep comfortable thermal environment.

3.3 Evaluation of thermal comfort based on the adaptive model

Fig. 9 gives the results of evaluation of the relationship between room temperature and outdoor temperature on a day in classrooms when cooling or heating systems are not used by applying the adaptive model (de Dear & Brager, 1998, ASHRAE Standard 55, 2004). In most cases when room temperature is 20 °C or higher, it is found that the relationship between room temperature and outdoor temperature is within 80% of the tolerance limit of the adaptive model. When room temperature is in the range of 20 to 30°C, outdoor air temperature is considerably lower than room temperature. If these results are combined with the relationship between indoor temperature and window opening ratio as given above, it is estimated that comfortable indoor conditions are maintained by the opening of windows and doors. When outdoor temperature is 30°C or higher, it is difficult to control the environmental condition because room temperature would be almost the same as the outdoor temperature.

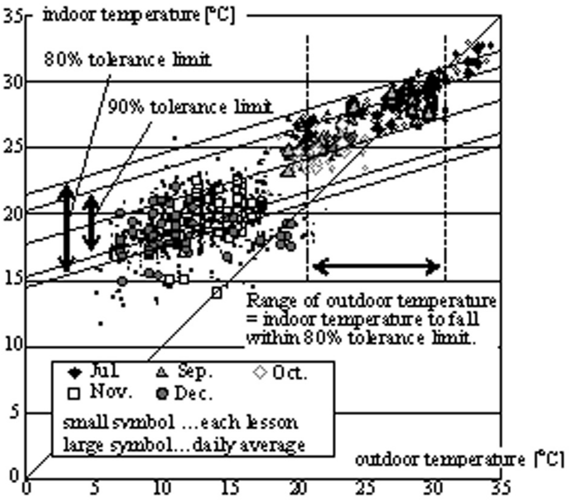

Figure 9. Evaluation of thermal comfort based on the adaptive model.

4. INDOOR AIR QUALITY

4.1 CO_2 concentration and opened area of windows and doors

CO_2 concentration and opening conditions of windows and doors caused by the operation of cooling systems in summer and opening conditions when heating system are used in winter are shown in Fig. 10 and Fig. 11 respectively. When cooling systems are not used in summer season, CO_2 concentration in rooms and corridors are low. When cooling systems are used, windows and doors are not opened all day long. As a result, CO_2 concentration is higher than 1500 ppm, which is the guideline value in school classrooms.

Similarly when windows and doors are not opened when heating systems are operated during winter season, CO_2 concentration exceeds the level of 1500 ppm. On the other hand, when windows and doors are opened only on corridor side to alleviate the influence on indoor thermal environment, the increase of CO_2 concentration is suppressed. This may be caused by the effects from the dilution of indoor air to corridors and may suggest the importance to perform evaluation of an inclusive and integral ventilation design including corridors and classrooms.

4.2 Frequencies to exceed guideline value of CO_2 concentration

Fig. 12 shows the frequencies where CO_2 concentration in classroom in each lesson hour exceeds the level of 1500 ppm in each month when cooling or heating systems are not used and when these are used. In July to October when cooling systems are not used, the CO_2 concentration does not exceed 1500 ppm in almost all cases. During the months of September and October when cooling systems are used, the concentration exceeds at the ratio of 80% or more. In December when heating systems are used, the frequency to exceed the guideline value is lower than that of the time when cooling systems are used, but is still close to 50%.

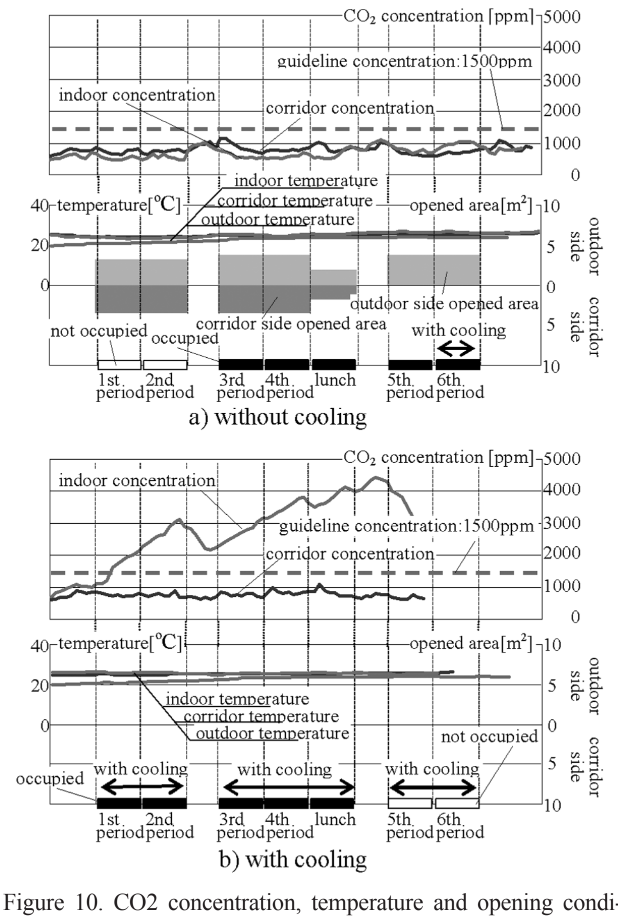

Figure 10. CO2 concentration, temperature and opening conditions of windows and doors in summer season. (school E, 30 Sep)

4.3 Relationship among airflow rate, opened area, temperature difference and wind speed

Fig. 13 and Fig. 14 each represents the relationship among wind speed through the opened area (ventilation rate / opened area) and temperature difference between inside and outside of the room and external wind speed. As wind speed, the values at the closest climate observation station, as converted to building height, are used. There is no definite correlation of wind speed through the opened area with temperature difference between inside and outside of the room. Also, no definite difference is found in the relationship with external wind. This may be due to the influence of pressure balance of the whole building airflow network.

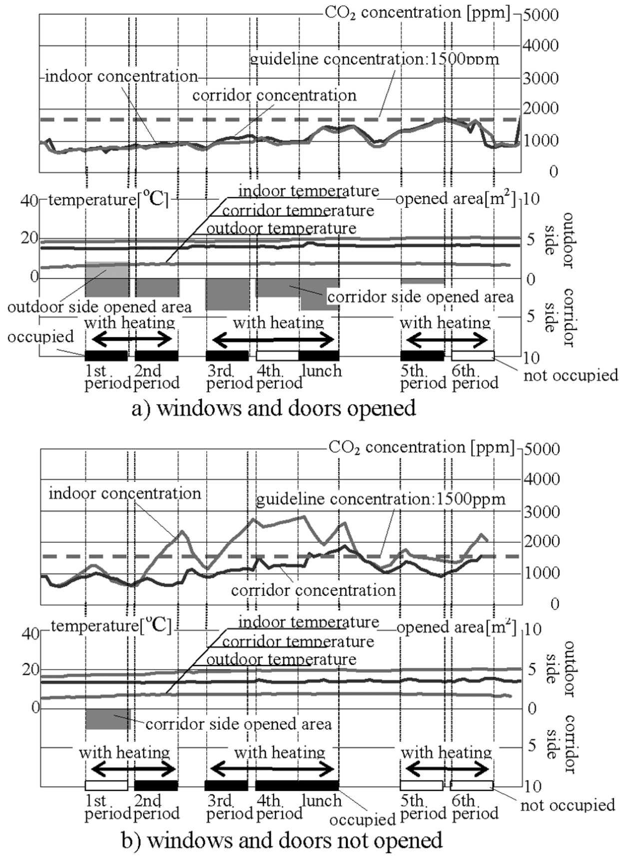

Figure 11. CO2 concentration, temperature and opening conditions of windows and doors in winter season. (school F, 12 Dec)

On the other hand, when attention is given on ventilation rate and opened area as shown in Fig. 15, the ventilation rate seems to increase approximately in proportion to the opened area. Using regression equation (Equation 1) shown in Fig. 15, we attempted to calculate the opened area necessary to maintain indoor CO_2 concentration at the level of 1500 ppm by estimating the quantity of CO_2 generated by the pupils and teacher in classroom. In case the number of pupils and teacher is 40 (39 pupils and 1 teacher), it is estimated that the opened area must be 0.4 m^2 in the classroom for lower grade pupils and 1.2 m^2 in the classroom for higher grade pupils.

5. CONCLUSIONS

The findings obtained from the results of the present study are as follows:

- If 80% of the tolerance of the adaptive model is applicable as the acceptable range of indoor thermal environment when cooling systems are not used, it appears that the necessity to use the cooling systems is low when outdoor temperature is 30 °C or lower.
- In order to maintain CO_2 concentration to a level lower than the guideline value when cooling systems are used, adequate measures must be taken, such as opening of windows, or operation of ventilation equipments.
- When windows and doors on corridor side are opened, the increase of indoor CO_2 concentration is effectively suppressed.
- Natural ventilation rate is well correlated with the opened area of windows and doors, while the correlation with the temperature difference or outside wind speed is poor.
- To maintain the indoor CO_2 concentration to a level lower than the guideline value, it is recommended to keep the opened area of windows and doors to 0.4 m^2 or more in the classroom for lower grade pupils and 1.2 m^2 or more for higher grade pupils.

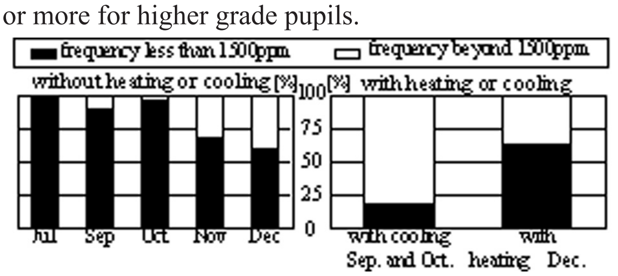

Figure 12. frequencies to exceed guideline CO2 concentration (1500ppm) with and without heating or cooling in each month.

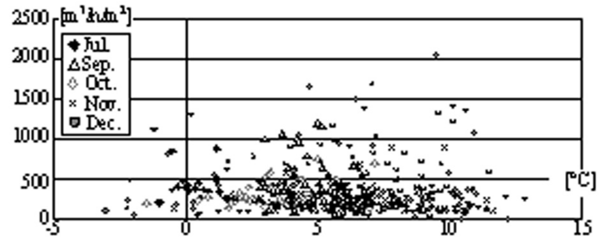

Figure 13. Relation between wind speed through opened area and temperature difference between inside and outside of the room.

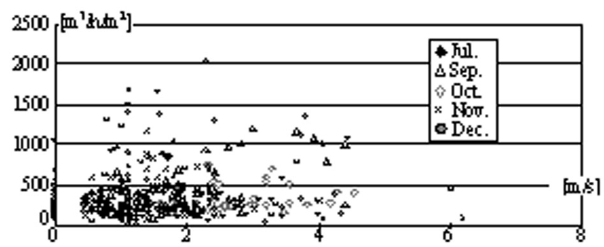

Figure 14. Relation between winds peed through opened area and external wind speed.

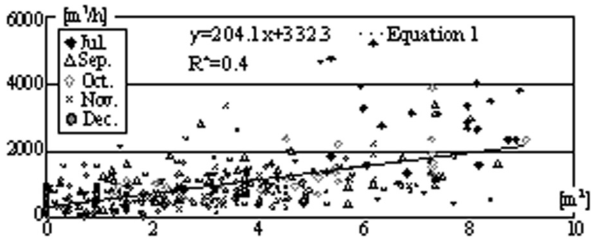

Figure 15. Relation between ventilation rate and opened area.

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