SCHOOL VENTILATION - GYMNASIUMS IN PRIMARY SCHOOLS

P. K. Eian[1], B. A. Børresen[1], L. Øie[1], B. R. Sørensen[2]

[1]Techno Consult AS, Sandvika, Norway
[2]Narvik Institute of Technology, Narvik, Norway

ABSTRACT

The main objective of this study was to determine the ventilation demand for a gymnasium in the primary school based on verified metabolic rate. Norwegian guidelines recommend 6.0 met as the activity level to be used when calculating the outdoor air flow rate in a gymnasium. Younger pupils have a lower body mass and metabolic capacity than adults, and their demand for ventilation is therefore lower. The metabolic rate has been assessed by measuring the pupils emission of the dominating bioeffluent CO_2 during intensive gymnastic activity. The emission of CO_2 was found to be 41 l/s per pupil which corresponds to an equivalent metabolic rate of 2.5. When allowing a maximum Predicted Percentage Dissatisfied (PPD) of 30% this gives an outdoor air flow of 17 l/s per pupil as a set point value, which is less than half of the 44 l/s per pupil based on design recommendations from the Norwegian guidelines.

INTRODUCTION

Metabolic rate is one of the main parameters for determining sufficient ventilation rates in occupied spaces. In gymnasiums this parameter is especially important because of the high occupation load. Metabolic rates for physical exercise can be found in several references. European guidelines [1] suggest a range from 3.0 - 10.0 met, and 6.0 for medium level exercise. 6.0 met has been the recommendation from the Norwegian authorities for gymnastic activity [2,3,4]. Based on established models for the calculation of ventilation requirements [1], a ventilation rate of 44 l/s per person is required when designing for a maximum Predicted Percentage Dissatisfied (PPD) of 30%.

System design includes cost aspects of installation, running and energy use, and should not compromise indoor air quality. However, younger pupils have a lower body mass and metabolic capacity than adults, and their demand for ventilation is therefore lower.

The scope of work is to determine ventilation demand for a gymnasium in the primary school based on verified metabolic rate during gymnastic activity performed by pupils.

An earlier study [5], covering air exchange efficiency during gymnastic activities has been done in a similar primary school, using tracer gas technique. These measurements showed only small differences between gymnasiums comprising the displacement ventilation principle and gymnasiums comprising the mixing ventilation principle. Additional measurements of CO_2 showed small differences between measuring points in the breathing zone and in the ventilation exhaust. However, there were several uncertainties in connection with the activity level in this study, and the study [6] presented in this paper was a follow-up study to obtain more valid data for calculation of the activity level for a worst case situation.

METHODS

The study [6] presented in this paper was performed at Tåsen primary school in Oslo. The study object was a newly renovated gymnasium comprising a balanced ventilation using the displacement principle.

The equivalent metabolic rate was assessed by measuring the pupils emission of the dominating bioeffluent CO_2. Worst case conditions were established by assigning pupils from the 7th grade (11 - 12 years) to perform intensive gymnastic activities throughout a full double lesson. The teacher was instructed to include all pupils in the activities. A full class meant 28 pupils plus 2 teachers in the class. Absent pupils were replaced with pupils from other classes.

Five consecutive tests were run with full classes. Each test lasted about 1.5 hours, and was the first gymnastic lesson that day.

CO_2 concentration was measured in the exhaust outlet using a photoacoustic gas monitor (Brüel & Kjær Multi Gas Monitor type 1302).

Air volumes were measured using a pitot static tube connected to a high accuracy micro manometer (Furness FCO 510). The layout of the ducts made it possible to perform good measurements of the outside air flow rate and the exhaust air flow rate. The air flow rates were checked during every test for variations in the air volumes.

RESULTS

The results from the Tåsen study are presented in figure 1, where CO_2 measurements from five double lessons are presented.

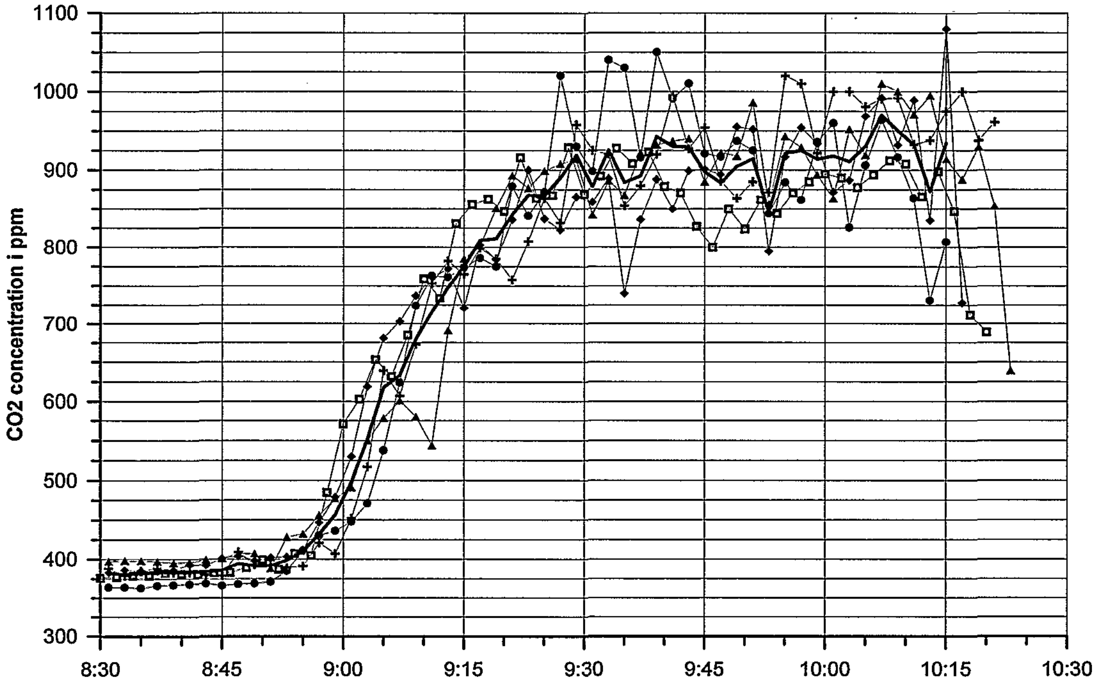

Figure 1. Results from the CO_2 measurements performed during in total 5 double lessons. The thick line represents the arithmetical average.

In addition to CO_2 concentration, an accurate determination of the outdoor airflow rate is necessary to calculate the indoor CO_2 production. Our measurements showed an outside airflow rate of 2100 m^3/h, which was far below the design value of 2.580 m^3/h and the contractors commissioning value of 2.500 m^3/h. The exhaust rate was measured to 1.800 m^3/h which indicated exfiltration from the gymnasium.

Calculation of CO_2 production and metabolic rate

From the results presented in figure 1 we have calculated the arithmetical average increase in the CO_2 concentration from the five tests to 580 ppm (Standard deviation 35 ppm). The two teachers were estimated to have an activity level of 2.5 met (low level physical activity). Based on tabulated values for physical exercise in European guidelines [1], the following connection between the emission S of CO_2 and the metabolic rate M can be derived:

$$S = 16.7 \cdot M \qquad [l/h] \tag{1}$$

For the teachers, their estimated activity level corresponds to a CO_2 emission of 42 litre/hour. The CO_2 emission per pupil can then be calculated:

$$S = \frac{2100 m^3/h \cdot 580 ppm \cdot 10^{-3} l/m^3 - 2 \cdot 42 l/h}{28\, pupils} = 41\ litre/hour \cdot pupil \tag{2}$$

Using equation (1), 41 litre/hour pupil corresponds to an equivalent metabolic rate of 2.5 met.

The olfactory load F can be calculated by using the equation [2]:

$$F = 2M - 1 \qquad [olf/person] \tag{3}$$

The average olfactory load from human bioeffluents per pupil is calculated at 4.0 olf. The total olfactory load from the 28 pupils plus 2 teachers is calculated at 120 olf.

Based on the general dilution formula [1], and the assumptions; Perceived outdoor air quality G_S of 0.1 decipol, which corresponds to a good air quality in towns and, Ventilation effectiveness ε_v of 1.0 equivalent to perfect mixing, the required outdoor airflow rate Q can be calculated as follows:

$$\dot{Q} = \frac{10 \cdot F}{(G_R - G_S) \cdot \varepsilon_v} \qquad [l/s] \tag{4}$$

This gives a required outdoor airflow rate of 17 l/s per pupil based on requirements for a maximum PPD of 30%, corresponding to a percieved indoor air quality G_R of 2.5 decipol.

The total requirement for outdoor air flow rate for 28 pupils plus two teachers is then 510 l/s corresponding to 1.850 m^3/h. The outdoor air flow rate required for dilution of emissions from building materials and interior adds to this.

DISCUSSION

The relatively simple experimental design in the Tåsen study was based on results from an earlier study [5] where similar measurements were performed. Measurement of CO_2 concentration in the earlier study showed small differences between measurement points in the breathing zone and in the exhaust. Hence, measurements of CO_2 in the exhaust is sufficient and even preferred to avoid local bias of local room concentration gradients.

The study was designed as a worst case situation, and hence gives the basis for set point values for constant airflow systems. All pupils were activated in football, field hockey, circuit training and other intensive activities with a minimum of breaks during the double lessons. The measurements indicate that the activity levels have been relatively constant with degree of variations with peak periods. In a normal situation, large groups of pupils are often split into two groups, alternating between intensive activity and rest. We used only pupils from the highest stage (11 - 12 years) in the primary school. Pupils in the lower stages can not be expected to have the same level of activity.

The study object comprises a ventilation system with the displacement principle. In the earlier study [5], measurements of the air exchange efficiency were performed in gymnasiums comprising both the displacement and the mixing principle. Our measurements were made using tracer gas during gymnastic activity and showed only small differences in efficiency for the two ventilation principles. Our recommendation is that both systems should be looked at as mixing ventilation systems with respect to their ventilation efficiency when the air flow rates are determined.

We have used the term equivalent metabolic rate to emphasise that this is a rate connected to adults with an average surface area of around 1.8 m^2. The constant 16.7 in the equation expressing the connection between the CO_2 production and the metabolic rate, is expected to be somewhat lower for the pupils. Hence our calculations of the metabolic rate would have been more in accordance with the design figures found for gymnastic activity. However, to compare the pupils real metabolic rate with national design guidelines [2], which refers to adults, equivalent metabolic rate is presented as if the pupils were adults.

All our measurements were performed with a full class of 28 pupils plus two teachers. When determining the set point for outdoor airflow rate due to bioeffluents, it is relevant to discount for an average number of absent or indisposed pupils. This is also considered in the draft proposal for the revision of the ANSI/ASHRAE standard 62-1989 where a discount of 2 out of 25 to account for normal absenteeism in classrooms is suggested [7]. For gymnasiums, we have in addition a number of indisposed people who are not participating in the gymnastic activities.

Ventilation design is usually based on unadapted visitors as the basis for the perceived indoor air quality. Adaption effects are moderate at high or moderate air quality levels, i.e. PPD typically below 30% [8].The procedure in a gymnasium is that the pupils always change clothes before entering the gymnasium. The dressing room usually has a high occupation load and hence gives a basis for adaptation. Due to fast adaptation to human bioeffluents we expect that the pupils are well adapted when entering the gymnasium. Any adaptation effect will, however, compensate for the lack of recovery time to be expected between following gymnastic lessons, and should therefore reduce the real PPD index of the occupants below 30%.

We want to emphasise that our use of recommended set point values is not the same as a design value. The set point value gives the basis for the outdoor airflow rate during gymnastic lessons for constant air flow systems. A design value is the basis for determining capacities of the air handling units and duct work. The design value can be higher than the set point value, where the design allows for other and higher loads, present or in the future.

Conclusion

We hereby conclude that the recommended set point based on the test results for the outdoor air flow rate due to bioeffluents for gymnasiums in primary schools is about 17 l/s per pupil. The outdoor air flow rate required for dilution of emissions from building materials and interior adds to this.

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