VENTILATION REQUIREMENTS AND ENERGY DEMAND OF CLASSROOMS

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Abstract

The paper deals with ventilation of school classrooms. Ventilation requirements according to different standards are discussed including the analysis of CO_2 concentration and pupil's age. For better understanding is presented relation between CO_2 and metabolit heat production. The ventilation energy consumption of classrooms and operation costs to provide adequate indoor air quality analysed in the paper. The calculations includes the forced and natural ventilation by windows during brakes period. Total operational cost (heat and electricity) for selected ventilation units depending on airflow rate is presented.

Keywords: *ventilation, school, pupils, energy consumption, classroom*

1 Introduction

In relation to massive reducing energy consumption by school buildings (windows replacement and insulation of facades) is indoor air quality in schools frequent topic recently. Most of schools has openable windows, which are very often inappropriately designed and in this case is natural ventilation not working well [3]. The biggest problem is in winter time, when is natural ventilation by windows almost suppressed. Pupils spend dominant time of day in one classrooms and poor indoor air quality (IAQ) has got impact to their attention, study results and health. This is confirmed by number of studies as for example ([1], [5], [6], [7], [8], [9], [12]).

According to the school facilities statistics (source: CSO [15]) attended nursery, primary and scondary schools approx. 1,6 mil. pupils / students (in year 2013 / 2014). From the statistics is not clear, how many school buildings has already finished steps for energy constuption reduction. But with reference to questionnaire survey [4] and focusing of govenment finnancial support is possible considered, that poor ventilation rates and indoor air quality problem is relating to signifiant number of schools. Questionnaire survey shows, that 54 % schools (from number of participating) has got energy consumption reduction steps already finished, in case of windows replacement and fasade insulation. Next 16 % has got these steps finished but together with heat source replacement.

Suitable solution is probably forced ventilation; however it has some need for energy consumption. The energy consumption is in terms of electricity need for air transport and heat energy for reduction of heating looses by supply air. This point is questionable, because theoriticaly natural ventilation should need more energy consumption for heating in comparing to forced ventilation with heat recovery exchangers.

Tab. 1 *School facilities statistics in Czech Republic, year 2013/2014 [13]*

School facilities	Number of facilities	Number of classrooms	Number of childrens/pupils/students
Nursery	5 085	15 390	363 568
Primary	4 095	42 334	827 654
Secondary	1 349	-	452 482
College	174	-	28 332

Note: Secodnary schools contains: gymnasiums, secondary technical schools, secondary vocational schools, conservatory

One of the main arguments againts proper ventilation of classrooms is energy demand and investment. IAQ and living conditions for childs (pupils / students) are up on other side. Ventilation (natural or forced) for sure brings some operation costs like energy consumption, maintanace costs and etc. Very often is possible meet opinion like „I will save a most of costs, when I will don´t ventilate“, it may seem in association to energy consumption reduction as reasonable, mainly when government hasn´t enough money for education in present time and also when is big pressure for buildings energy consumption reduction. This issue is in fact more extensive, there is all societal impact and it is connected to other sectors such is medicine, education, industry and etc. The healt care costs resulting from poor IAQ is very difficult calculate and is mostly impossible to use this argument for improving indoor environments in schools.

2 Ventilation design

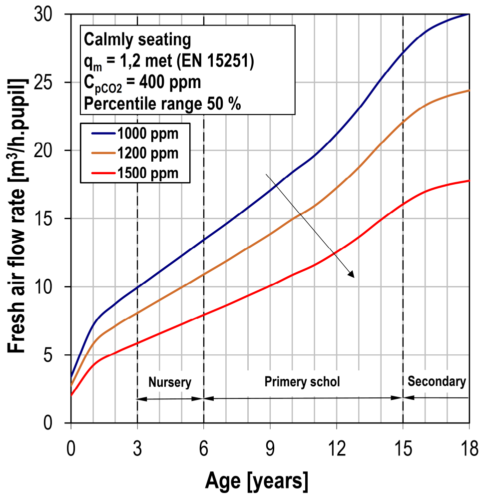
2.1 CO_2 production by pupils

As indicator of IAQ is very often used concentration of CO_2 and it is because carbon dioxide is metabolite with very good features in terms of measuring. Production of metabolit CO_2 depends on human activities and physical proportions (weight, height). Production of CO_2 is then lower during low activities as calmly seating comparing heavy physical working or sporting activities. It´s similar like for heating production by human body, which is radiated into enviroment. Carbon dioxide production can be calculated from modified equation (source: ASHRAE [1]):

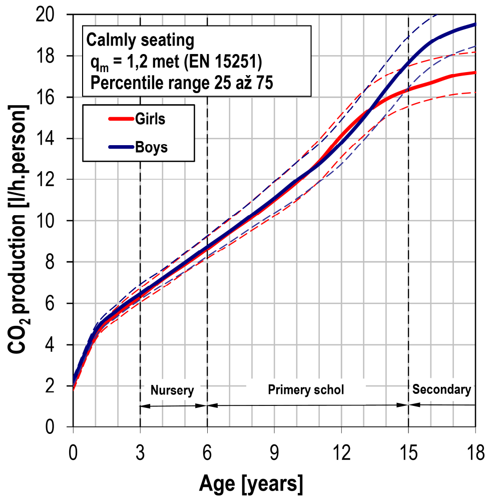
$$V_{CO2} = 1,742 H^{0,725} W^{0,425} M \quad \text{[l/h]} \tag{1}$$

where H is height of the body [m],
W weight of the body [kg],
M metabolic heat [met].

By equation (1) can be determinated CO_2 production for specific activity and for specific physical proportions of human body. Weight and height of child body can be provided by growth charts (percentile), which are used for growing control of childs body by peditriacians. Standard avarage is 50 % percentile. Fig. 1 shows CO_2 production depending on children age in percentile range from 25 to 75 % for physical activity 1,2 met (calmly seating – classroom).



a)



b)

Fig. 1 *a) CO_2 production depending to children age, b)Fresh air flow rate for 1 pupil on the base of CO_2 balance in indoor enviromental*

2.2 Ventilation air flow rate assessment by CO_2 production

Required fresh air flow rate can be determined by balance of CO_2 concentration in indoor ventilated room. Required air flow rate is to ensure limited CO_2 concentration in indoor enviroment. Fig 1b) shows air fresh flow rate according pupil age on the base of different levels in education system for limited CO_2 concentration 1000 ppm (Pettenkoffer limit), 1200 and 1500 ppm. CO_2 concentration in outdoor air was considered as 400 ppm. In clasroom is except pupils at least 1 teacher, for who is classroom working place and therefore ventilation design must respect this condition.

Some selected standards (tab. 2) and decrees set up limited CO_2 concentrations in classrooms. Tab. 2 shows summary of selected standards with required air flow rates of supply fresh air. Recalculated air flow rates on the base of indoor ventilated room balance are shown in tab. 3 (according to previous considerations). From the results is evident, that Austrian standard ÖNORM H 6039 is using similar approach. All air flow rates are set up with consideration of indoor ventilated room balance, age of pupils and limited CO_2 concentration.

Tab. 2 *School ventilation requirements by choosen standards*

Standard	**Limited CO_2 concentration [ppm]**	**Air flow rate per pupil [m³/h.pupil]**			
		3 – 6 let	**6 – 10 let**	**10 – 15 let**	**15 – 18 let**
		Kindergarden	**Primary school**	**Primary school**	**Secondary school**
Czech national decree no. 343/2009 Sb.	-	20 – 30			
ČSN EN 15251	1200	-	14 to 36		
ÖNORM H 6039:2008	1200	-	15	19	24
VDI 6040-1	1000	-	26	31	31

Tab. 3 *Air flow rates set up on the base of indoor ventilated room balance, age of pupils and limited CO_2 concentration, C_e = 400 ppm (as on fig 2)*

IAQ	Limited CO_2 concentration[ppm]	Air flow rate per pupil [m^3/h.pupil]			
		3 – 6 let	6 – 10 let	10 – 15 let	15 – 18 let
		Nursery school	Primery school	Primery school	Secondary school
I. – high	1000	12	17	25	27
II. – middle	1200	9	12	18	20
III. – acceptable	1500	7	9	13	15

2.3 Heat production

Heat production [W] of human body can be calculated with using equation determinating surface of human body (DuBois 1916 [1]) and specify relation with CO_2 (Fig. 2). Metabolic heat (1 met = 58 W/m^2) is as suitable criterion for comparison between these two dependings. And it is because follows actual activity of person. Fig. 2 (left) shows relation metabolit heat production and CO_2. CO_2 production significantly increase lineary with higher physical activity. For boys it higher comparing girls, because they have bigger physical proportions then girl. Ventilation requirements (air flow rates) then results from dependences shown on fig. 2 with corresponding physical activities. For beter reading is on fig. 2 added heat production relation and age of pupils (on right).

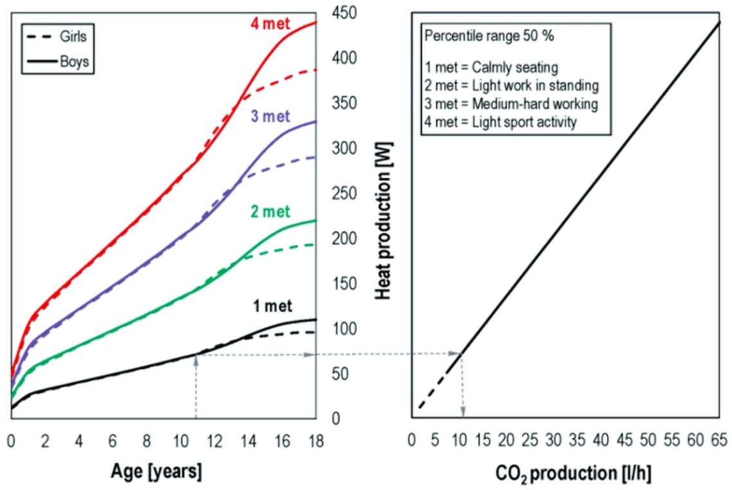


Fig. 2 *CO_2 production relation to heat production of human body, age and activity*

3 Energy demand for ventilation

In following chapter is done analysis of energy demand for classroom ventilation. The analysis provide demand of electricity for air transport (fan power input – forced ventilation) and generally heat demand for different variants.

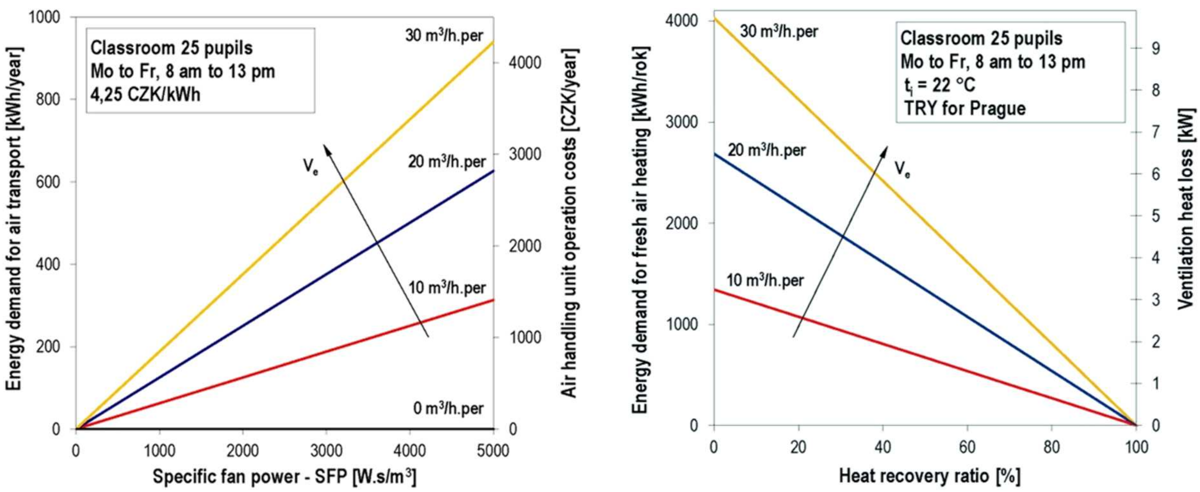
3.1 Test case

The test case use typical classroom with 25 pupils and 1 teacher. Indoor air temperature is establish as constant t_i = 22 °C, room volume is 204 m^3. Ventilation is nonstop in time of using classroom. It is ordinary working day from 8am to 1pm (expect all holidays). We follow previous chapter (10, 20 a 30 m^3/h.person) for air flow rates and heat recovery ratio. Indoor and outdoor heat gains are not taken into final balance. As weather data is used TRY for Prague (test reference year). The TRY represent real characteristic weather conditions for building energy demand calculation. Minimum outdoor air temperature in TRY is -16.5 °C.

3.2 Electricity demand for air flowrate

Electricity consumption by fan motors depends on power input, which is depending to flow rate, external pressure and fan motor efficiency. As suitable parameter for estabilishing energy consumption is fan power input characteristic. It is relation of power input and air volume flow rate. Energy demand for air transport by airhandling unit (AHU) E_{el} can be calculated from AHU total power input P and operation time τ. Following this idea is offering as good graphical representation specific fan power parameter *SFP*. This parametr contains power input and flow rate as well.

Fig. 4b shows analysis results in relation of energy demand by fan power input to SFP with actual air flow rate V (10, 20 a 30 m^3/h.person). Energy demand is proportionally encreasing to fan power input ($P = SFP.V$). Fig. 3a quantifies energy demand for air transport including annual costs. Electricty demand is mainly done by type of used fan motors, flow rates per pupil are following to pupil age. Therefore is important to pay bigger attention to air handling selection. Values higher than SFP > 5000 are not preseneted.



a) *b)*

Fig. 3 *a) energy demand for air transport including annual costs, b) energy demand by fan power input to SFP with actual air flow rate per pupul (without heat input from fan motor)*

3.3 Energy demand for supply air heating

Results of heat energy demand relation to air flow rate for pupil and heat recovery ratio are presented on fig. 3b. Results are for classroom test case. Fig. shows influencing factors. Current situation for energy consumption reduction, when is fresh are flow rate as minimum (it´s going to be almost zero) is satisfactory. But from view of IAQ is alarming.

On the base of current situation in school facilities [4], is heat loss by ventilation covered by heating system and ventilation system is designed as natural by windows. In case that natural ventilation will follow mandatory standards, it is pernament ventilation (rates from 20 to 30 m^3/h.pupil) [13], must be done design of heating system for 6 to 10 kW to cover heat loss by ventilation (supply air temp. is as outdoor air temp.). However it is from point of energy consumption impossible. Heat loss by transmission is thanks facade insulation and windows replacement minimum and very often covered by indoor heat gains.

Forced ventilation with heat recovery is one from possibilities how to save energy for supply air heating in case that target is to keep IAQ in requested standards. Energy demand for heating of fresh air is shown on fig. 3b. It depends on heat recovery ratio.

3.4 Costs for supply air heating

Following previous chapters is on fig. 4 shown approx. costs for supply air fresh heating relating to heat recovery ratio and price of primery energy from 300 to 700 CZK/GJ (500 CZK/GJ = 1,8 CZK/kWh). To final finance balance is entering heating of air by fan motor as well (included). The price of primary energy is changed on the base of type. We mentioned central heating system which is used at 1/3 of school facilities [4]. Boundary conditions are as for test case with consideration that air flow rate is 20 m^3/h.per. When air flow rate drops by half, drops by half also costs and etc.

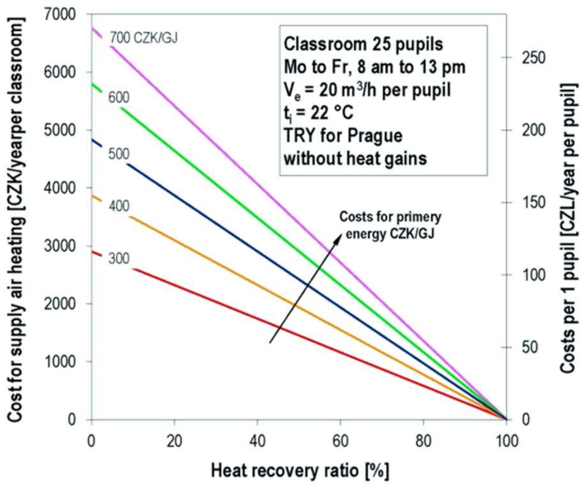


Fig. 4 *Cost for supply fresh air heating relating to heat recavery ratio and costs for primery energy*

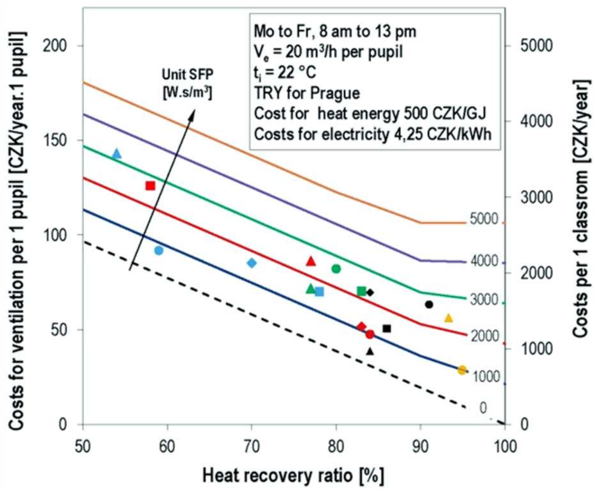


Fig. 5 *Total costs for ventilation per 1 pupil – points in graph represent specific air handling units (1 € = 27,5 CZK)*

4 Total costs for ventilation

Fig. 5 shows total annual costs for forced ventilation of one classroom related to 1 pupil with air flow rate 20 m^3/h, different *SFP* and heat recovery ratio. General dependencies are valid for defined cost for energy in chapters above. Total cost include costs for fan motor and heating of supply fresh air.

Air handling units analysis

Points in fig. 5 represent costs by specific air handling units. For purpose of this article were analyzed 17 decentral units with heat recovery available on Czech market (further without detailed specification), with nominal air flow 500 m^3/h. Units were choosed for purpose of energy consumption calculation without any further analyzes. Fig. 5 shows, that most of units reach values of *SFP* up to 3000 W.s/m^3.

When is used real unit, are real costs with decentral air handling unit and heat recovery in wide range from 29 to 143 CZK/year per pupil. It depends on type of unit and *SFP* respectively heat recovery ratio. From analyzes is easy visible, that higher standard of air handling unit brings saving of operation costs.

5 Conclusion

Presented analyzes shown, that costs for supply fresh air and air transport by forced ventilation system (without maintanance and labor cost) in classroom (decentral air handling unit with heat recovery and flow rate 20 m^3/h.person) are from 29 to 143 CZK/year (1 € = 27,5 CZK) per 1 pupil on the base of unit type. Avarage cost is 71 CZK/year per 1 pupil. This cost should be as negligible part of budget. The question is, what approach have founders for this issue and what are social priorities. Every founder should in any case follow valid standards and laws.

The time payback is question, which is very hard responsibly answer. If is calculated energy consumption by using annual price increase, the payback time is about 20 years and more. Problem is, that standard methods how to calculate payback time is impossible to use. It is because this issue includess related social and financial aspects. As is for examply cost for childrens health care, parents absence in job etc. The argument, that for healthy indoor enviroment must be paid is not correct. The main problem for solution of IAQ in schools is investment. Investment is very often too high and only one way for founders is to ask for some local grants.

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