DOI: 10.14621/tna.20160206

Architectural Design of Schoolrooms while taking into Account the Requirements of Thermal Comfort

Mária Budiaková

Slovak University of Technology in Bratislava, Faculty of Architecture
Nám. slobody 19, Bratislava, Slovakia; budiakova@fa.stuba.sk

Abstract

The paper is oriented on architectural design of schoolrooms while taking into account the requirements of thermal comfort. Correct disposition solutions of schoolrooms will enable the provision of thermal comfort and also in the ventilation of schoolrooms. Correct and sufficient ventilation of schoolrooms is very important because students and pupils spend in the schoolrooms the majority of their time in school. In our schools the ventilation is incorrect and insufficient. The biggest problem is winter period when the ventilation is provided only by opening the doors to corridor. This way, there is insufficient intake of oxygen, which causes distractibility and feeling of tiredness of pupils. In current schoolrooms we can use only natural ventilation and thus the schoolrooms have to be ventilated using windows. Therefore this research was focused on the comparison and the analysis of different systems of natural ventilation in schoolrooms. The experimental measurements were carried out in schoolroom, where the parameters of thermal comfort were measured in the different systems of natural ventilation with device Almemo 2590 which was connected to computer. Gained values of air temperature, air velocity and index PMV are presented in graphs. On the base of analysis of measured values were evaluated the systems of natural ventilation for schoolrooms. Correct architectural solution of schoolroom corresponding to fulfil the thermal comfort with optimal system of natural ventilation was designed. In the future, the mechanical ventilation in schoolrooms can be assumed, therefore the recommendation on modern energy saving system of mechanical ventilation is in the end of this paper. Proposed architectural solution of schoolroom also suites for modern energy saving system of mechanical ventilation.

Keywords:	Architectural design; Disposition solutions; Thermal comfort; Natural ventilation

Article history:	Received: 18 April 2016 Revised: 19 July 2016 Accepted: 01 August 2016

1. Introduction

Architectural design of schoolrooms must also take into account the requirements of indoor climate. In terms of indoor climate, it is important to provide thermal comfort and sufficient ventilation in schoolrooms. Architectural design of schoolrooms must take into account, that also during ventilation in schoolrooms, the thermal comfort was provided. In old school buildings is very difficult rather impossible to provide thermal comfort and sufficient ventilation, what also relates to incorrect architectural design. The biggest problem is that during ventilation the thermal comfort in schoolrooms is not kept. Thus thermal discomfort in schoolrooms arises mainly during ventilation, what causes sickness of students and teachers. Therefore, new school buildings should have such architectural design that would enable provision of thermal comfort and sufficient ventilation of schoolrooms in high quality.

In the schoolrooms, ventilation means the exchange of the air in room for the fresh outdoor air. In Slovakia, common schoolrooms are using only natural ventilation in which the air stream occurs as a consequence of equalization of pressure difference, which is caused by natural forces. Insufficient supply of oxygen, high concentration of CO_2, excessive air humidity, various types of odors, toxic pollutants, aerosol and microbial pollutants threatens pupils when there is insufficient ventilation of schoolrooms. It can cause distractibility and feeling of tiredness, various skin diseases, respiratory diseases, emergence of allergies, emergence of oncological diseases and so on. Therefore, the sufficient ventilation of schoolrooms is very important because students and pupils spend in schoolrooms the majority of their time in school. The biggest problem is winter period when the ventilation is provided only by opening the doors to corridor.

Provision of thermal comfort parameters in schoolrooms is very important, therefore sufficient ventilation cannot be at its expenses. Thermal comfort in schoolrooms is defined as the state of mind that expresses satisfaction with the surrounding environment. The fundamental quantities for evaluation of thermal comfort are internal air temperature, operative temperature, globe temperature, air relative humidity and air velocity [1]. Then thermal comfort is evaluated with index PMV (Predicted mean vote) and index PPD (Predicted percentage dissatisfied) [2], [3]. Incorrect ventilation and thermal discomfort in schoolrooms during ventilation contribute to high sickness rate of students mainly in winter [4]. Incorrect ventilation also increases energy intensity of schoolrooms, which causes the problem in the effort of achieving the zero energy buildings in the future [5].

In Slovak school buildings, the ventilation is incorrect and insufficient [6]. Architectural design of existing schoolrooms is such, that contributes to creation of thermal discomfort and it mostly does not allow sufficient ventilation. Therefore, this research was focused on providing thermal comfort and the analysis of different systems of natural ventilation in schoolrooms in relation to architectural design. There were carried out the experimental measurements in schoolroom, where the parameters of the thermal comfort were evaluated in different methods of natural ventilation using windows. It was pointed out on the principles of correct architectural design of schoolrooms in relation to methods of natural ventilation.

2. Analysis of architectural design of schoolrooms in relation to thermal comfort

The research was focused on general schoolrooms, which are furnished with basic furniture, with tables and chairs, taking into account the ergonomic requirements of students. The research was not focused on technical schoolrooms and laboratories.

Architectonic correct arrangement of tables in schoolroom is very important from many points of views but also in terms of satisfying the parameters of thermal comfort. Tables might have typical two row arrangement, continuous arrangement, arrangement in the shape of U, possibly another arrangement. Architectonic correct arrangement of tables must ensure that the local thermal discomfort will not arise. Local thermal discomfort (the thermal dissatisfaction) can also be caused by unwanted cooling or heating of one particular part of the body [2]. The most common cause of local thermal discomfort is draught but local discomfort can also be caused by an abnormally high vertical temperature difference between head and ankles, by too warm or too cool floor, or by too high radiant temperature asymmetry. People are most sensitive to radiant asymmetry caused by a warm ceiling, a cool wall (windows, glazed facade), cool ceiling or by a warm wall. The major problem in schoolrooms is with cool windows, therefore their surface should be minimized just to provide daily lighting. In order to eliminate local thermal discomfort between external wall and desks, there must be met the minimal distance 1,00 m, as it is in Figure 1 [7]. Architectural incorrect arrangement of tables in schoolroom is in Figure 2 [8] and Figure 3 [9], where the local thermal discomfort arises.

Schoolrooms in Slovakia are heated by convective heating elements. In schoolrooms must be fulfilled minimal value of operative temperature 20°C, which is related to thermal comfort.

Figure 1. Minimal distance 1 m between external wall and desks

Figure 2. Architectural incorrect typical two row arrangement of tables

Figure 3. Architectural incorrect arrangement of tables in the shape of U

(a) (b)

Figure 4. Architectural location of tables and door in schoolroom
a – Incorrect position, b – Correct position

In relation to thermal comfort, the next important requirement in schoolrooms is the provision of air exchange 20 m – 30 m^3/hour per student. This exchange of air in Slovakia is provided only with different systems of natural ventilation. The most used is natural ventilation with opening the window or opening the window and the door. For providing these systems of natural ventilation, door must be architectural designed in the correct position to tables and last window. Important is that there is sufficient air exchange during breaks. At the same time, it is important that in the zone between last window and door, where local thermal discomfort is arising because of high air velocity (feeling of draught), are not placed tables for students and for teacher. Therefore, door must be in the back part of schoolroom, where there are no tables. In Figure 4 [9], [10] are tables and door in architectural incorrect position and correct position.

3. Research of thermal comfort in schoolroom in relation to architectural design

Research of thermal comfort in schoolroom in relation to architectural design continued with measurements of natural ventilation systems. Experimental measurements were carried out in schoolroom - Figure 5, Figure 6 at the Budapest University of Technology and Economics, Faculty of Architecture in March 2015.

3.1. Methodology of research

Thermal comfort was researched by three ways of natural ventilation in schoolroom in comparison with the state after the ventilation:

a. After the natural ventilation, closed windows and door – Figure 5;

b. Ventilation method, opening the window I – Figure 8;

c. Ventilation method, opening the window II – Figure 9;

d. Ventilation method, opening the windows I and II and the door – Figure 7.

The aim of measurements was to record the parameters of the thermal comfort: air temperature, air relative humidity, air velocity, globe temperature and index PMV in three types of natural ventilation. Measurements were carried out in schoolroom - Figure 5 in two height levels 1,10 m – Figure 9 and 1,65 m – Figure 7 in standpoints:

A – Figure 6, Figure 8,

B – Figure 6,

C – Figure 6, Figure 9,

D – Figure 6, Figure 7.

Opening part of the window has dimensions 700 x 1400 mm.

Figure 5. Schoolroom after the natural ventilation a.

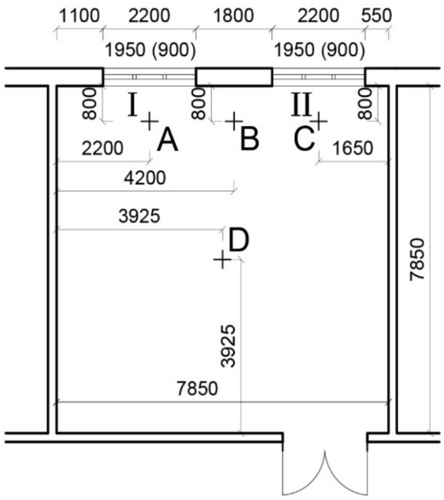

Figure 6. Schoolroom with standpoints

Figure 7. Ventilation method d. in schoolroom, standpoint D, level 1,65 m

Figure 8. Ventilation method b. in schoolroom standpoint A

Figure 9. Ventilation method c. in schoolroom standpoint C, level 1,10 m

The parameters of thermal comfort were recorded with device Almemo 2590 which was connected to computer. Input data in measurements were: metabolic rate 1,0 met, clothing insulate 1,0 clo. Measurements were done in two height levels, which enabled the change of tripod (measurements were not carried out in height level 0,10 m, since the tripod was not capable of it) on which temperature and humidity sensor, globe thermometer and turbulence sensor were attached. Twenty measurements with time delay (one by one) were carried out in each standpoint and in each height level. Statistical mean was calculated from measured values. Measurements were carried out one by one in individual standpoints and in individual height levels. Schoolroom was heated by two convective heating elements located under the windows.

Outdoor air temperature was measured and recorded by separate device. Outdoor air temperature increased during the measurement from value 14 °C to value 19,8 °C. During the measurement the sunlight was at first intensive on the window I and later on the window II.

Measurements could be carried out only without the students in the schoolroom because of spatial capabilities. Therefore, it did not make sense to scientifically investigate other parameters of air quality in individual types of natural ventilation.

Ventilation of type b. and c. – opening of one window did not provide sufficient air exchange in the course of five minutes (duration of break between lessons). Ventilation of type d. – opening of both windows and door provided sufficient air exchange in the schoolroom during break. It was found out on the basis of questionnaire survey with students, which used this schoolroom.

3.2. Analysis and results of research

The values of air temperature are figured by individual types of natural ventilation, in standpoints A, B, C, D in the height level 1,1 m in Figure 10 and in height 1,65 m in Figure 11.

The values of air velocity are figured by individual types of natural ventilation, in standpoints A, B, C, D in the height level 1,1 m in Figure 12 and in the height 1,65 m in Figure 13.

The values of index PMV (Predicted mean vote) are figured by individual types of natural ventilation, in standpoints A, B, C, D in the height level 1,1 m in Figure 14 and in the height 1,65 m in Figure 15.

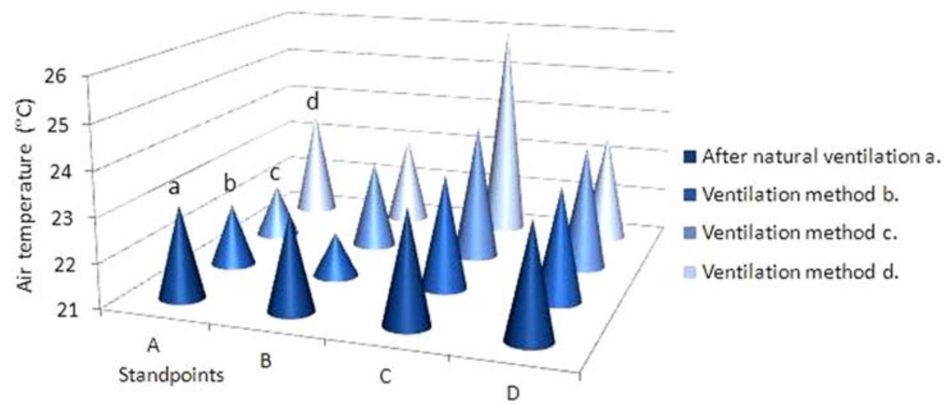

Figure 10.
Values of air temperature
in the height level 1,10 m

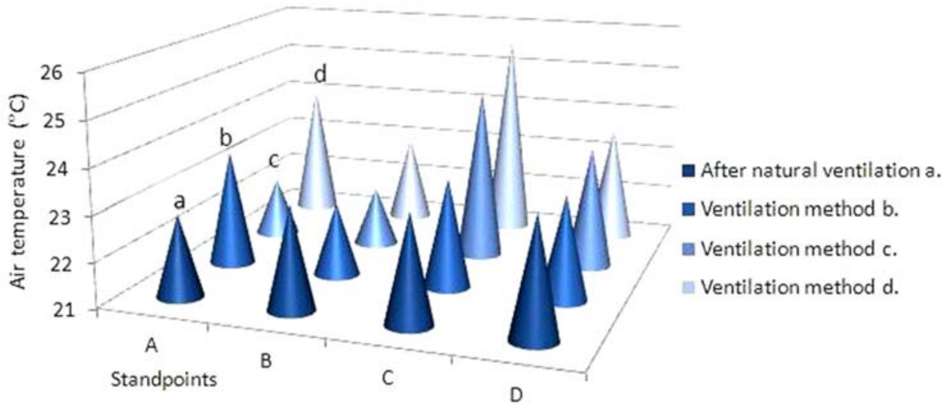

Figure 11.
Values of air temperature
in the height level 1,65 m

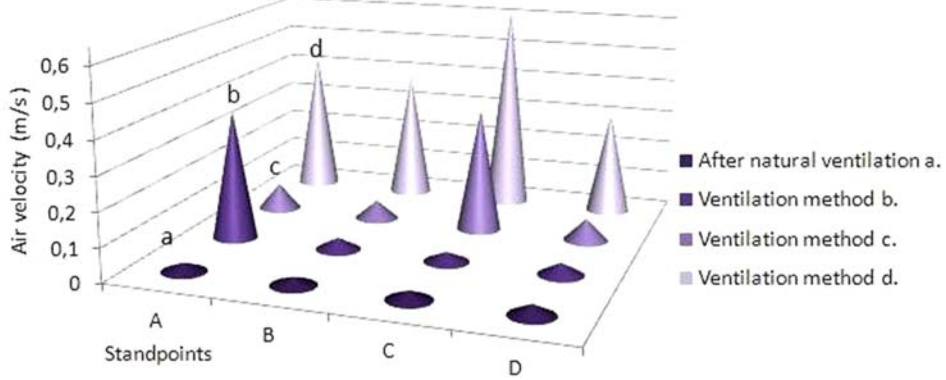

Figure 12.
Values of air velocity
in the height level 1,10 m

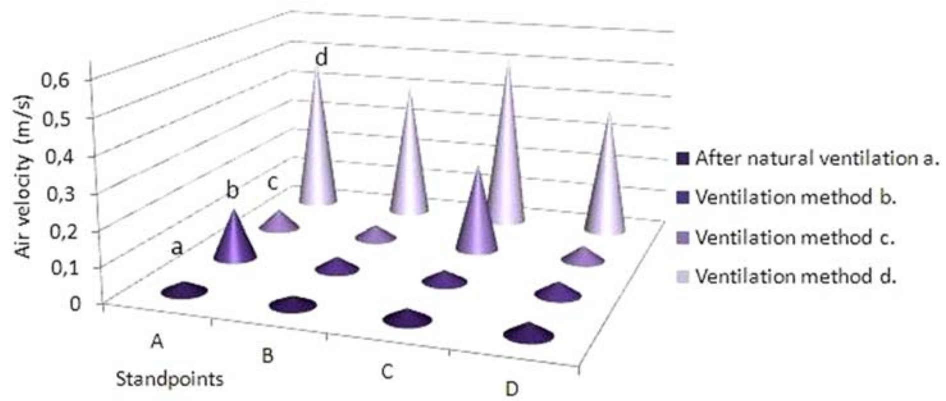

Figure 13.
Values of air velocity
in the height level 1,65 m

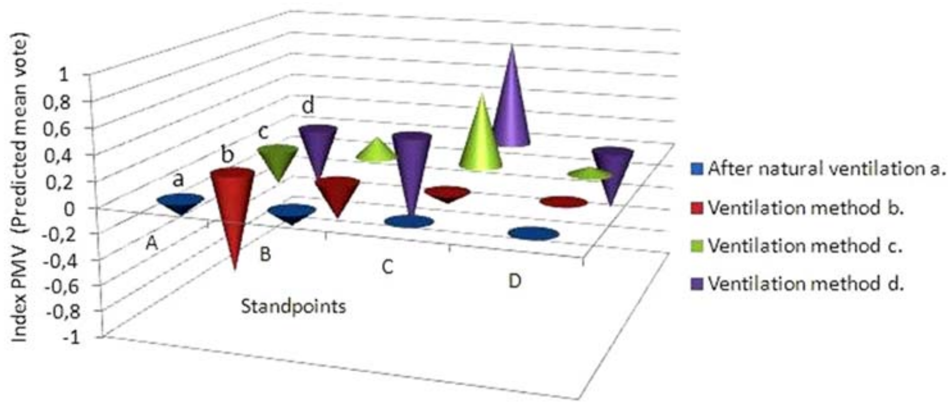

Figure 14.
Values of index PMV
in the height level 1,10 m

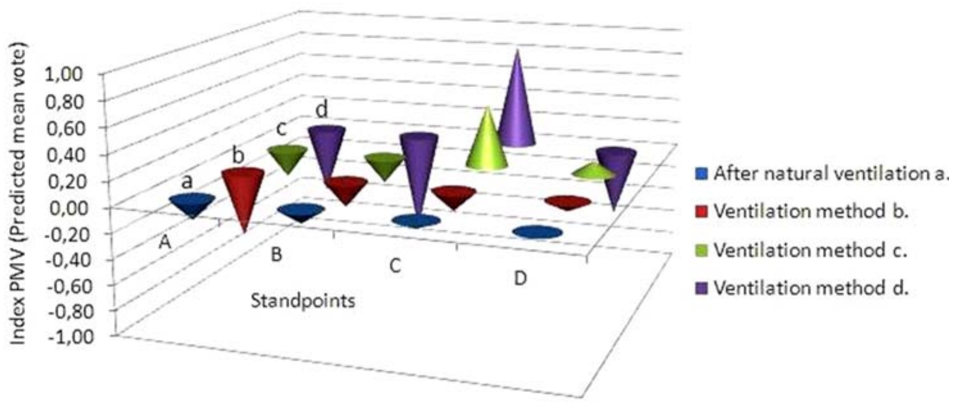

Figure 15.
Values of index PMV
in the height level 1,65 m

3.3. Discussion

Air temperature in schoolroom in measurement a. was even in individual standpoints and in two height levels. In measurements b., the lowest air temperature was in standpoint A, which was caused by the opened window I and the highest air temperature was in standpoint D. In measurements c., there was intensive sunlight on the window II, which caused the highest air temperature in standpoint C regardless of opened window II. In measurements d., the sunlight on window II was so intensive, that despite of opened windows and door the air temperature was noticeably high in standpoint C. The differences of air temperature in the two height levels were adequate to convective heating.

Air velocity in the schoolroom in measurements a. was even and suitable in individual standpoints, in the height level 1, 65 m was slightly higher, which was caused by convective air stream. In measurements b., the air velocity increased to unbearable value in standpoint A in the height 1,1 m, which was caused by opening the window I. In measurements c., the air velocity increased noticeably to unbearable value in standpoint C in the height 1,1 m, which was caused by opening the window II. In measurements d., the air velocity increased noticeably to unbearable value in all standpoints and in the both height levels. It was proved that the student cannot sit when the window is opened and it is impossible to sit nor stand in schoolroom when both of the windows and door are opened.

Index PMV in the schoolroom in measurements a. was optimal in individual standpoints and in the two height levels. In measurements b., the index PMV reached the inadmissible value ([2], [11]) in standpoint A in the height 1,1 m, which was caused by opening the window I. In measurements c., the index PMV had admissible values in standpoint C in the both heights, which was caused by opening the window II, the inadmissible values did not emerge as a consequence of intensive sunlight. In measurement d., the index PMV had inadmissible values in standpoint C and B, it did not reach the optimal value in other standpoints.

Experimental measurements showed, that in efficient natural ventilation in schoolroom - opening the windows and the door in the zone between windows and door, where local thermal discomfort arise because of high air velocity (feeling of draught), cannot be placed tables for students and for teacher. Therefore, door must have architectural correct position - Fig. 7. It means that door must be in the back part of schoolroom and between the last window and door cannot be placed tables for students.

4. Conclusions

Architectural design of schoolrooms must also take into account requirements for thermal comfort and ventilation. Important is that the architectural design of schoolrooms will allow to provide the thermal comfort also during ventilation. In Slovakia, the common schoolrooms use only natural ventilation. Existing schoolrooms have such architectural design that does not create conditions for sufficient natural ventilation. Moreover the insufficient architectural design contributes to creation of local thermal discomfort.

Experimental measurements confirmed that none of the investigated methods of natural ventilation is appropriate for schoolroom in terms of thermal comfort. In case of measuring in lower outdoor air temperature, the results would noticeably confirm the inaptitude of natural ventilation in connection to thermal comfort. Ventilation of type d. – opening of both windows and door provides sufficient exchange of air in schoolroom, but the thermal comfort is markedly violated and thus the students cannot be in the schoolroom during the ventilation in each break after one teaching hour, what is unreal. In new schoolrooms with natural ventilation, the correct architectural design is inevitable, which should include also the correct position of tables for students and teacher, correct position of door towards windows and tables. Such architectural design might contribute to thermal comfort also during ventilation of schoolroom.

The most appropriate solution for new schoolrooms is controlled forced ventilation with heat recovery system. Investment expenses for this forced ventilation system are higher, but the sufficient air exchange is achieved, the thermal comfort and energy saving is provided. In such modern system of forced ventilation, the influence of architectural design would be significantly smaller.

Acknowledgements

Paper is published with the support of grant agency KEGA, grant n. 039STU-4/2014.

References

[1] Bánhidi L., Kajtár L., *Komfortelmélet, Comfort Theory*, Muegyetemi kiadó, Budapest, Hungary, 2000, p. 436.

[2] Standard STN EN ISO 7730 Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria.

[3] Standard STN EN ISO 7726 Ergonomics of the thermal environment. Instruments for measuring physical quantities.

[4] Etheridge D., *Natural Ventilation of Buildings*, John Wiley & Sons, United Kingdom, 2011, p. 454.

[5] Voss K., Musall E., *Net Zero Energy Buildings*, EnOB, München, 2012, p.192.

[6] Kožuchová, M.: *Elektronická učebnica didaktika technickej výchovy, Electronic Textbook-Didactic of Technical Education*, Online, Univerzita Komenského, Bratislava, 2011.

[7] http://www.lencos.sk/img/page/skolsky_nabytok/skolsky/002.jpg

[8] http://proeling.sk/blog/31-ozvucenie-skoly

[9] http://www.mydva.sk/jazykove-ucebne.html

[10] http://www.zsmoravtn.edu.sk/galeria/skola/skola.htm

[11] Standard STN EN 15251 Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics.