Evaluation of indoor air quality in classrooms equipped with different methods of ventilation

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Abstract
Natural ventilation through windows is the main source of air supply in the majority of UK schools.. Designing a window that enhances the air flow into a space in order that fresh air and thermal comfort are provided without compromising daylight and attenuating background noise level is very challenging. The aim of this study is to evaluate the impact of using different ventilation methods on classroom air quality and assess how different ventilation methods can also affect other comfort factors. In this study CO\textsubscript{2} levels of eight classrooms equipped with different methods of ventilation are recorded in four primary schools located in the West Midlands, UK. Pupils’ perceptions about classroom air quality, speech intangibility and the level of light on the working plan were also established. Results confirm that classrooms equipped with cross, stack and mixed mode ventilation perform better compared to those that have single sided ventilation due to a higher satisfaction rate and lower CO\textsubscript{2} level. Mixed mode ventilated classrooms perform better acoustically and in terms of providing thermal comfort in winter. Pupils from stack ventilated classrooms are more satisfied with the level of light on their working plane compared to other classrooms.

Keywords: Single side ventilation, Cross ventilation, Stack ventilation, Mixed mode ventilation, Air quality, Thermal comfort, Acoustic comfort, Primary School, Classroom

1 Background
The health and performance of students and teachers are influenced by the internal environment of school buildings such as air quality (Haverinen-Shaughnessy et al., 2015), noise levels (Shield and Dockrell, 2008), indoor temperature (Parsons, 2014) and light levels (Heschong et al, 2002). One of the main reasons that schools fail to provide high quality learning environments is the lack of optimisation of different internal environmental factors and design features that could respond to all comfort factors holistically (Montazami et al, 2015).

For example, the majority of UK schools are naturally ventilated through windows and in some cases this approach can lead to significant problems (Montazami et al, 2012). This is related to the fact that windows act as a source of heat gain and heat loss, transfer daylight into the building, remove hot air, maintain levels of fresh air and also attenuate background noise levels. Furthermore, windows are an architectural element which allows the occupants of a building to experience the external environment, interact with it and also add an identity to a building.
Montazami et al (2015) introduce the Environmental Circle (Figure 1) which shows a close relationship between comfort factors.

![Environmental circle and relation between comfort factors (Montazami et al, 2015)](image)

The lines on this circle represent the conflict between comfort factors through the history of UK schools since the Victorian era. One of the main reasons for this conflict is poor ventilation through single side windows. Ventilation is one of the key parts of school design as it has a direct effect on the indoor air quality and thermal comfort as well as an indirect link with other comfort factors. Consequently, it is important that innovative techniques are used in designing windows in order to maintain the relationship between comfort factors and minimise potential conflicts.

The concentration of CO₂ can be used as a good approximation of indoor air quality (IAQ) in learning spaces (Mendell and Heath, 2005). High CO₂ levels in classrooms in primary schools can have a negative impact on academic performance (Bakó-Biró et al, 2012) and long exposure can impact health and development.

The aim of this study is to compare the performance of conventional single side ventilation to cross, stack and mixed mode ventilation and understand how these different methods affect our ability to maintain the relationship between air quality and acoustic comfort, lighting comfort and thermal comfort.

2 Methodology

This paper is a part of a large case study assessing the indoor environmental quality of primary schools located in the West Midlands, UK. In order to evaluate the impact of different ventilation types on indoor air quality, this study uses both objective and subjective data from 8 classrooms of four primary schools which were equipped with different means of ventilation system during the cooling and heating seasons of 2014. The indoor CO₂ levels were recorded every ten minutes with EXTECH CO210 CO₂ monitors and data loggers (Accuracy: ± 5% of reading + 50 ppm). In these classrooms, pupils’ air quality sensation was evaluated by asking them to vote if a classroom is ‘Stuffy, Ok, Fresh, Very Fresh’ or ‘Smelly, Ok, Not smelly, Not smelly at all’. In both cases pupils have an option to vote ‘I can’t tell’ if they do not have any idea about the indoor air quality. 192 pupils participated in this study.

Some classrooms were selected to evaluate the impact of ventilation method on visual and acoustic comfort. In these classrooms, pupils’ perceptions about acoustic comfort are
evaluated by asking them to rate speech intangibility and how well pupils hear their teacher and vote ‘Very difficult, Difficult, Ok, Easy or Very easy’. The sources of background noise that pupils may hear when they are inside the classroom were also questioned.

The visual comfort was also evaluated by asking pupils how well they can see their working plane and to vote ‘Very difficult, Difficult, Ok, Easy or Very easy’.

Schools, classrooms and the number of pupils who participated in this study and the ventilation types are presented in Table 1.

Table 1 Summary of all the collected data

<table>
<thead>
<tr>
<th>School</th>
<th>Classroom</th>
<th>School year</th>
<th>Ventilation type</th>
<th>Number of respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.1</td>
<td>4</td>
<td>Single sided ventilation</td>
<td>23</td>
</tr>
<tr>
<td>1</td>
<td>1.2</td>
<td>5</td>
<td>Single sided ventilation</td>
<td>23</td>
</tr>
<tr>
<td>2</td>
<td>2.1</td>
<td>5</td>
<td>Cross ventilation</td>
<td>26</td>
</tr>
<tr>
<td>2</td>
<td>2.2</td>
<td>6</td>
<td>Cross ventilation</td>
<td>24</td>
</tr>
<tr>
<td>3</td>
<td>3.1</td>
<td>3</td>
<td>Stack ventilation</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>3.2</td>
<td>6</td>
<td>Stack ventilation</td>
<td>26</td>
</tr>
<tr>
<td>4</td>
<td>4.1</td>
<td>5</td>
<td>Mix mode ventilation</td>
<td>26</td>
</tr>
<tr>
<td>4</td>
<td>4.2</td>
<td>6</td>
<td>Mix mode ventilation</td>
<td>24</td>
</tr>
</tbody>
</table>

The characteristics of each school equipped with different methods of ventilation are explained below.

**Single sided ventilation:** School One is a 1970s conventional single sided, naturally ventilated school building using a fan heater in winter. Two classrooms of C1.1 and C1.2 are selected from this school. C1.1 has a north-west orientation, and C1.2 has south-west orientation with secondary window wall facing south west. C1.1 has large glazing areas with no internal or external shading but has anti-glare filters fitted on the glass panes. C1.2 has internal blinds and rather small windows. Figure 2 shows internal and external view of the school building. As it can be seen, the internal blinds that protect the inside from glare may reduce the classrooms potential for having natural ventilation.

![Fig 2. Single side naturally ventilated school](image)

**Cross ventilation:** School Two naturally, cross ventilated building built in 2009. Two classrooms of C2.1 and C2.2 are selected from this school. Both of these classrooms face north and are located on ground and first floor respectively, one on top of the other. Both have cross ventilation through the roof vents that can be operated through a switch and also windows that can be operated manually. Stack affect helps the cross ventilation. Windows consist of small top-hung windows and a larger window (or door on the ground
floor), narrow safety ventilation panels, and large areas of fixed glazing inside the classroom. Both classrooms have movable wall partitions to adjacent classrooms.

![Image](image_url)

**Fig 3. Cross ventilated school through roof vents and windows**

**Stack ventilation:** School Three is naturally cross ventilated through stack affect and was built in 2011. Two classrooms C3.1 and C3.2 are selected from this school. Each classroom has a large window facing south and high level windows facing north that facilitate the stack ventilation and increase the lighting level. High-level windows are automatically operated and there are override switches in each classroom. An overhang with horizontal louvres offers partial external shading. Both classrooms are on the ground floor and have doors with glazing to the playground.

![Image](image_url)

**Fig 4. Stack ventilated school through windows on both side**

**Mixed mode ventilation:** School Four is a Passivhaus building constructed in 2013, run on mixed mode ventilation in the cooling season and mechanical ventilation with heat recovery in the heating season. Two classrooms of C4.1 and C4.2 are selected from this school. In summer fresh outdoor air is provided in the classroom via the mechanical ventilation system, but users open the windows as needed, to cool down. In winter, the MVHR supplies pre-heated air in the classroom. All windows are manually operated, both classrooms have large ventilation panels and small bottom hung windows at desk level. Both classrooms are on the first floor. The orientation of the classrooms’ window wall is south and north respectively. There is no external shading to the north. The roof eve projects out by about 80 cm offering shading in summer. C4.1 receives light from both sides through fixed high-level windows and the main window. One of the south side windows is replaced by a panel in order to facilitate air flow without introducing excessive solar gains as well as providing secure night time ventilation.
3 Analyses
3.1 Impact of different ventilation systems on classroom indoor air quality

In this part the impact of different methods of ventilation are compared through objective and subjective surveys. The pupils’ perceptions of different comfort factors as well as recorded CO₂ levels are compared in different classrooms equipped with different methods of ventilation.

Objective survey: Figure 6 shows the range of CO₂ levels in different classrooms equipped with different methods of ventilation. As can be seen, the range of CO₂ level in classroom with single side ventilation is significantly higher compared to the CO₂ level in other classrooms equipped with other means of ventilation. The range of CO₂ level in classrooms equipped with mixed mode ventilation is significantly lower compared to others.

Figures 7 and 8 show the CO₂ concentration profiles for two weeks in summer and winter. The levels of CO₂ in both summer and winter generally are higher in single sided ventilated classrooms compared to the classrooms with other means of ventilation.
Subjective survey: Pupils’ perception is evaluated by asking them to vote about freshness and the smell of the classroom. According to the regression analysis carried out between the pupils’ perception about freshness/smell of the classrooms and the daily average CO₂, perceptions in terms of freshness (P<0.05, R² = 0.05, Freshness) better represent the quality of the classroom compared to the perception related to smell (P<0.05, R² = 0.01, Smell). However, pupils have a better understanding about the smell of the classroom rather than freshness of the classroom and it is easier for pupils to vote about smell rather than freshness.

Figure 9 shows the distribution of pupils’ perception about the freshness of their classrooms according to the method of ventilation. In the classrooms equipped with cross, stack and mixed mode ventilation, less than 14% of occupants feel stuffy while this figure
reaches 50% in single sided ventilated classrooms. As an example, unusually primary school classrooms have around 28 students. According to this finding in single sided naturally ventilated schools it is likely that 14 pupils feel the classrooms is not fresh while this figure can be reduced significantly to 2 pupils in classrooms equipped with other means of ventilation.

This figure also emphasis that the numbers of pupils who are satisfied with freshness of the classrooms are around 80% in stack and mixed mode ventilated classroom.

![Figure 9. Pupiles perception about in dor air quaily based on freshness scale](image)

Figure 10 shows the distribution of pupils’ perception about the smell in their classrooms according to the method of ventilation. All the classrooms equipped with cross, stack and mixed mode ventilation are not smelly and pupils who voted Not smelly to Not smelly at all are significantly higher in these classrooms compared to the single sided ventilation classroom.

![Figure 10. Pupil’s perception about indoor air quaily based on smell](image)
Pupils’ perception about the freshness and smell of classrooms which are represented in Figures 9 and 10 correlate the range of CO₂ in classrooms equipped with different method of ventilation.

3.2 The impact of method of ventilation on lighting and acoustic comfort

This part highlights how innovative methods of ventilation may have a positive impact on other comfort factors such as acoustics, lighting and thermal comfort.

3.2.1 Mixed mode ventilation and acoustic comfort

In order to assess the impact of having mixed mode ventilation on acoustic comfort in classrooms, pupils are asked to vote how easy they can hear their teacher. Both of the schools have a considerable distance to the road with heavy traffic.

In classrooms with mixed mode ventilation systems all pupils can hear their teacher without any difficulty while in classrooms that have single sided ventilation 10% of pupils have difficulty in hearing their teacher (Figure 11). In addition, in the classrooms equipped with mixed mode ventilation nearly 80% of pupils found communication Easy to Very easy while this percentage drops to 40% in the single sided ventilated classroom.

In single sided ventilated classrooms around 90% of pupils hear noise from outside (i.e. car and people taking) while this reduces to 20% in schools equipped with mixed mode ventilation system.

![Fig 11. Acoustic perception in single side and mix mode ventilation system](image)

This result suggests that classrooms equipped with mixed mode ventilation have a better acoustic comfort due to the lower background noise level as it is not necessary to open the window for ventilation purposes.

3.2.2 Mixed mode ventilation and thermal comfort in winter

Using the mix mode ventilation not only has a positive impact on acoustic comfort but also has a positive impact on indoor air quality during the heating season.

When the outside temperature is decreasing the level of CO₂ is increasing in single side and stack ventilated classrooms while it is not the case for classrooms equipped with mixed mode ventilation (Figure 12). This result confirms the fact that in classrooms equipped with mixed mode ventilation, there is not any conflict between achieving indoor air quality and thermal comfort as there is no need to open the window to maintain indoor air quality.
3.2.3 Stack ventilation and lighting comfort
In order to assess the impact of stack ventilation on lighting comfort, pupils are asked to vote about how easy they can see their working plane. In the stack ventilated classrooms, two windows at both sides let light in from both sides. Although classroom 3.1 is equipped with a mixed mode ventilation system, it is designed to receive light from both side (Figure 5- right).

Pupils from the classrooms equipped with stack ventilation or mixed mode ventilation (that have windows on both sides of the classrooms) do not have any difficulty to see their working plane while nearly 10% of pupils from single side ventilated classrooms which receive light from one side have difficulty to see their working plane (Figure 9). In addition the number of pupils who find their working plane is either easy or very easy to see are less in single sided ventilated classrooms compared to other classrooms.

4 Discussions
The results indicate that CO₂ concentration and pupils’ perception about the quality of indoor environment is significantly better in classrooms equipped with stack, cross and mixed mode ventilation system compared to single side ventilated classroom. Results also suggest that although pupils have a better understanding about the classrooms’ smell
compared to the freshness, asking about their perception of freshness is a better indicator of a classroom's indoor air quality.

Results also suggest that stack ventilated classrooms perform better with regard to lighting comfort compared to single sided ventilation systems as they receive light from two sides. In addition, classrooms perform better with regard to acoustic comfort and achieving thermal comfort for both winter and summer and also lighting comfort with some amendment.

5 Conclusions
Designing and delivering a classroom that is resilient to future climate change and uncertain future requires innovative solutions that could response to various needs. This paper is a part of large case study assessing the quality of indoor environment in primary schools located in West midlands, UK equipped with different methods of ventilation. Studies show that one of the main reasons attributed to the poor indoor environment in the history of UK schools is the lack of optimisation of different internal environment factors of thermal comfort, lighting comfort, acoustic comfort and indoor air quality.

The focus of this study is examine that how different methods of ventilation influence the air quality in learning environments and also help balance the often conflicting requirements of thermal, acoustic and lighting comfort.

Results suggest that single side ventilation is less likely to deliver good indoor air quality and also it is very challenging to satisfy all the comfort factors through a simple window design solution. The other methods of ventilation that should be considered in the future of school designs are stack, cross ventilation or mix mode ventilation.

Acknowledgments
This study is part of the Knowledge Exchange and Enterprise Network (KEEN) project between Architype and Coventry University, led by the University of Wolverhampton and funded by the ERDF and Architype. We are grateful for the assistance from the head-teachers and staff of the case study Primary Schools. External weather information was kindly provided by the Met Office.

References


