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The Sustainable School: Effective and Energy Efficient Ventilation in the Classroom, and the Question of Educational Performance and Wellbeing

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Abstract: *Within the context of designing a sustainable school, technical studies that address questions of air quality, educational performance and wellbeing, challenge the trend towards designing for natural ventilation in schools. This paper critically examines research literature that has provided evidence that temperature and air quality are, in a large proportion of classrooms, so poor as to have a negative effect on children's health and educational performance. This evidence, in support of mechanical systems that control air quality, contradicts trends towards natural ventilation proposed in order to conserve energy consumption in schools. Indoor Air Quality (IAQ) is generally not stressed, or indeed challenged, in the program to design sustainable schools, but the questions of air quality, children's wellbeing in school and educational performance, raise important issues in the drive to reduce energy consumption of schools.*

Keywords: Sustainable Schools, Indoor Air Quality, Educational Performance, Natural Ventilation, Health, and Wellbeing

Responding to the increased problem of air pollution, at crisis point in cities such as Shanghai and Paris; the Parisian philosopher Luce Irigaray has argued for air pollution to be considered a crime against humanity.[1] In Paris, air quality has been so poor this year that the city has offered residents free public transport, appealing to car drivers to leave their vehicles at home. The elderly, children, asthmatics and people with heart problems being advised to stay indoors to avoid breathing problems. [2] Last year, the international press commented on a building trend in China to provide school children with covered air conditioned play areas in response to concern over air quality in cities. One private school, the International School of Beijing installing a $5,000,000 domed structure over the playground.[3] In Chinese cities, the media broadcasts air quality reports warning residents on days where levels of pollutants in the air pose a risk to the health. The Shanghai Air Pollution: Real Time Air Quality Index website provides daily information about air quality which at the time of writing was rated as very unhealthy with an AQI of 230.[4] In the winter of 2012, international news services noted that for 38 days the air quality in Shanghai was so bad that city authorities advised residents to stay indoors. Comparisons are made between these levels of pollution and passive smoking, and to put this into perspective, the Air Quality Index (AQI) measurements in the northeastern part of China reached more than 1,000 micrograms (µg) per cubic meter, where anything above 300 is considered extremely hazardous (the US AQI only goes up to 500).

Calculating the Health Risks of Air Pollutants

To calculate the AQI requires a measurement of air pollutant concentrations either, from a monitor or from a computer model. The function used to convert these concentrations to the AQI, however, varies by pollutant and moreover, from country to country. In the US, AIQ is calculated as a measure of five pollutants: ground-level ozone (O_3), atmospheric particulate matter, carbon monoxide (CO), sulfur dioxide (SO_2) and nitrogen dioxide (NO_2). But in the

UK, the index is based on the concentrations of five different pollutants: O_3, $PM_{2.5}$ (atmospheric particulate matter, also known as particulates, with an aerodynamic diameter of less than 2.5 μm), PM_{10} (particles with an aerodynamic diameter less than 10 μm), SO_2 and NO_2. In China, on the other hand, the AQI levels are based on six atmospheric pollutants: O_3, PM_{10} and $PM_{2.5}$, CO, SO_2 and NO_2 (measured at the monitoring stations throughout each city). Hence, different countries have their own air quality indices, which are not all consistent, and different countries use different names for their indices, such as, Air Quality Health Index, Air Pollution Index and Pollutant Standards Index. Nevertheless, there are standardized public health advisories associated with each AQI range, from "good", through to "unhealthy for sensitive groups", to "very unhealthy" and "hazardous".

The most dangerous of air pollutants are the atmospheric particulate matter, the smallest being PM_{10} and $PM_{2.5}$, tiny pieces of solid or liquid matter suspended in the atmosphere as a particulate/air mixture or aerosol. Sources of this particulate matter can be anthropogenic, that is to say man-made, or natural (such as volcanic dust and water mist). Researchers have estimated that 470,000 deaths a year occur due to human-caused increases in O_3 levels but 2.1 million deaths are caused by particulates, especially the smallest $PM_{2.5}$ that can penetrate deep into the lungs and are attributed as the cause of cardiopulmonary disease and lung cancer. Many of these deaths occur in China and South East Asia where populations are high and pollution is severe.[5] Furthermore, in 2013, a Danish study, involving 312, 944 people in nine European countries argued that there was no safe level of particulates, and that for every increase of 10 $\mu g/m^3$ in PM_{10} the lung cancer rate rose by 22%. The smaller $PM_{2.5}$ gave a 36% increase in lung cancer per 10 $\mu g/m^3$.[6] Hence, the burden globally of anthropogenic outdoor air pollution on present-day premature human mortality is now one of the most urgent environmental risk factors for human health.

The dome fitted over the playground of the International School of Beijing, of a similar type used to cover sports fields for winter use, incorporates a custom made air filtration system to remove these particulates. The AQI rating inside the dome, measured on four consecutive days in January 2013, in terms of particulate matter, was found to be in the 0 -10 $\mu g/ m^3$ range in comparison to 105 - 405 $\mu g/ m^3$ outside the dome.[7] Air-supported structures, like these, have been widely used to cover sports and recreation fields across the world for winter use; but these specific structures, the first of which enclosed Dulwich College in Beijing in 2012, have now developed as a unique phenomenon to address serious issues of outdoor air pollution and the danger it poses to children within a normal school day.

Anthropogenic air pollution is causing a serious risk to human health all over the world. Industrial processes, fossil fuel burning power stations, diesel fuel in vehicles, are all contributors. Inhabitants of Chinese cities that can afford expensive private education are sending their children to schools with covered, air conditioned, air quality controlled play spaces and governments in Europe are providing financial incentives of free transport on "smog days" to dissuade city inhabitants from using cars. [8] Wider government legislation tackling the cause of emissions is, however, barely noticeable. Irigaray, in response to the

Parisian air pollution crisis argues that serious environmental questions are being forgotten. As an active and working philosopher, a leader in her field, she writes that whilst air, by its nature, evades any exploitative efforts from man to make it a commodity, our pollution of it and lack of legislation, describes a profound abuse of others which characterizes our environmental crisis. The question this raises is difficult: how do we fundamentally change our intentions towards each other, rethink our relationality to our natural environment and its inhabitants, and act to alleviate these pollution issues? What about our responsibility to future generations, and indeed to the current generation and their health and wellbeing? But outdoor air pollution is not the only source of abuse being caused to human respiratory systems. More than half of the body's intake is inhaled indoors and many illnesses related to environmental exposure to pollutants are related to Indoor Air Quality (IAQ). [9]

Indoor Air Quality (IAQ) in Schools

Indoor Air Quality (IAQ) refers to the air quality in and around buildings as it relates to the health and comfort of building users. IAQ can be affected by CO, Radon (Rn), Volatile Organic Compounds (VOCs), PM_{10} and $PM_{2.5}$, and microbial contaminants (such as mold and bacteria) CO_2 and even asbestos fibres. CO can derive from space heaters and defective central heating boilers or furnaces, and particulates, especially the most dangerous $PM_{2.5,}$ can be found arising from tobacco smoke. Rn, an invisible, radioactive gas, is emitted from rock formations, and is a serious hazard for indoor air in homes in the United States and Europe. VOCs are gases that include a variety of chemicals which are known to have short and long-term adverse health effects. Examples of materials that give off such compounds include: paints and lacquers, paint strippers, cleaning supplies, pesticides, carpets, furnishings and building and construction materials. CO_2 is an indoor pollutant (for the purposes of IAQ) exhaled by humans, correlating with human metabolic activity. CO_2 is an air pollutant where at unusually high levels it may cause occupants to grow drowsy, to get headaches, and to function at lower mental activity levels. Whilst it is a significant concern for IAQ in schools and offices, it cannot be the sole concern for classrooms when considering the health, wellbeing and educational performance of children, especially when designing sustainable schools raises particular issues because of the need to reduce energy consumption and use energy efficient materials.

In a recent study comparing the IAQ in classrooms in a Victorian school in London, with a new energy efficient school in the same city, researchers found high levels of pollutants in both schools. Whilst the Victorian school classrooms relied on high infiltration rates of outdoor air and on natural ventilation strategies (which would be typical of a school building in the UK of this age) and the energy efficient "low carbon" school adopted a mechanical extract with a CO_2 sensor; indoor concentrations of NO_2 (a cause of asthma and other respiratory illnesses in children) in the Victorian school exceeded annual World Health Organization (WHO) 2010 guidelines of $40 \mu g/m^3$ [10] One classroom ranging from 35.6 to $41.2 \mu g/m^3$. But in the energy efficient school NO_2 levels were three times higher at 9.1-13.9 $\mu g/m^3$. [11]

In a study of Serbian schools, comparing indoor and outdoor air quality, concentrations of pollutants found included: PM_{10} and $PM_{2.5}$, polycyclic aromatic hydrocarbons (PHAs) exposure to which is associated with asthma, VOCs, formaldehyde (CH_2O), O_3, CO_2 and NO_2. It was found that in one that PM_{10}, $PM_{2.5}$ and PHAs (byproducts of fuel burning) were higher in indoor environments than in outdoor. Moreover, the average value of CH_2O, (a carcinogen) was, in all classrooms, significantly higher than the recommended value. In this particular study authors recommended an extensive program of school renovation. [12] However, in a study of schools in Lisbon, researchers examined levels of $PM_{2.5}$ and PM_{10}, in classroom in comparison to levels outdoors, and determined that these pollutants did not pose the same health risks as outdoor air pollution as they emanated from different sources including, skin particles, soil materials from childrens' shoes and chalk from the blackboard. They argue that determining risk requires an analysis of particulate composition. Nevertheless, they did find high concentrations of Zinc (Zn) in particulate form and attributed it to products used to protect steel, wood surfaces, doors and windows.[13] In another study, this time of Michigan schools (68 schools in total) whilst ventilation rates were found to be poor in classrooms, and although bioaerosols (mold particles) and VOCs were present at higher levels than outdoors, pollutants were not at problematic levels.[14] Sources were science rooms, art rooms and indoor pools. The solution, designs to prevent the migration of these pollutants throughout the school.

Nevertheless, new sustainable schools have performed less well. Levin writes that IAQ concerns have suffered due to a lack of a comprehensive assessment methodology. Guidance or rating systems fail as sustainable design requires a system for the evaluation of building performance to address trade-offs between human and non-human health and wellbeing. [15]Persily similarly argues that whilst some discussions of energy efficient buildings include the need for non-energy performance attributes such as IAQ, most discussions tend to focus on energy performance and reliance on minimal standards is not sufficient. Moreover, Demand Control Ventilation (DCV) – increasingly being employed in sustainable buildings – is particularly problematic in terms of IAQ. [16]

IAQ and Sustainable Schools

That all people should have free access to air and water of acceptable quality is a fundamental human right and children are more vulnerable to airborne pollutants than adults, because their developing lungs breathe more air compared with their bodies, and due to their relative inability to communicate concerns in response to pollutant levels. Environmental exposures to high levels of pollution can have long-term adverse consequences for children. The WHO recognized the right to clean air with the publication in 1987 of air quality guidelines containing risk assessments for 28 chemicals, but it was not until 2010 that guidelines for IAQ were established and authors argue that the underlying reason was the difficult question of how to enforce air quality standards indoors? [17] Perhaps, it is not surprising that even when children are more vulnerable to pollutants than adults, in the example of school buildings, the air inside schools can be more polluted than the air outside. However, for the new and sustainable schools, this should not be the case. IAQ can be controlled by reducing the causes of contaminants in the air (source control) – which is within the realm of the designer at least in the choice of building materials and finishes – by air filtration, the increased use of ventilation and increased air exchange rates to dilute contaminants, but in the case for the sustainable school there is a deeper problem concerning a mistaken disregard for the broad range of factors contributing to IAQ because of the need to reduce the energy performance of the school.

IAQ and Educational Performance

Numerous studies have determined the effect of IAQ on health, and it is not difficult to project that absence days caused by illness will impact upon educational performance. [18] What is significant is evidence also of the effect of pollutants on cognitive performance, in addition to health. [19]

Past studies have been carried out to examine the influence of thermal conditions and air quality on children's ability to carry out their schoolwork. [20] But until research carried out in ASHRAE 1257 – TRP there was no evidence that classroom air quality would improve educational performance. [21] ASHRAE 1257 demonstrated that children's ability to perform schoolwork is dependent on classroom air quality, but that most classrooms are so poorly ventilated that even CO_2 concentrations, routinely reach 1500- 2000 ppm. Children in the air-conditioned classrooms performed schoolwork slightly better than children in an adjacent classroom, naturally ventilated during a period of warm weather. [22] Research carried out in ASHRAE 1257 – TRP, quantified this, and proposed that each doubling of the outdoor air supply rate in the classroom would result in an increase of 14.5% in the performance of schoolwork. Moreover, each reduction of classroom air temperature by 1°C (1.8ºF) during warm weather resulted in an increase of 2% in the performance of schoolwork.

Importantly for approaches to designing sustainable schools, ASHRAE 1257 – TRP proposed that a classroom with windows that can be opened, even if this is the most desirable ventilation option, does not guarantee good air quality, because teachers and children are so often unable to perceive poor air quality – CO_2 levels or even humidity – and children often lack the authority to take steps to improve it to open windows themselves. Building management issues can be a factor in this sort of failure of a ventilation strategy in schools, automatically opening windows triggered by a monitor to open them, being "turned-off" as posing a distraction to the teacher. [23] Openable windows in the same school required a key of which there was only one shared between a number of classrooms. Other good reasons for teachers not opening classroom windows when air quality is low, include loss of thermal control, cold downdrafts that cause uncomfortable thermal gradients, wind that blow papers around, external noise that distracts attention as well as increased use of energy in the heating season.

Designers of sustainable schools are dependent on guidelines but need a critical perspective. Schools require both indoor and outdoor educational spaces, classrooms and playgrounds, and both demand good air quality. Sustainable schools are not only about energy performance, but must include health and wellbeing. Architects have to respond to new findings, and about good air quality in schools, not only as CO_2 levels or prohibiting pollution entering the classroom for outdoor sources; but also in terms of indoor causes of air pollution. Performance assessment methodologies to include targets for energy performance and IAQ would allow designers to begin to work to achieve performance in both but school communities need ways of enforcing standards. Whilst, pollutants cause illness, and days away from school, and influence educational performance, improving education performance must be a priority for all new school building programs. Indoor air quality cannot be a neglected factor in the design of sustainable schools.

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