Original Article

Indoor climate and its impact on atopic conditions in Maltese school children

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Abstract

Several studies on the prevalence of allergic conditions have identified that allergic conditions are on the increase worldwide. The aim of this study was to assess the effect of classroom humidity and temperature levels on schoolchildren in Malta. Our cohort included 191 children. Standardised ISAAC health questionnaires were answered by the children's parents. Lung function tests, acoustic rhinometry, exhaled nitric oxide (NO), exhaled carbon monoxide (CO) and nasal lavage were performed on the participating children. School building characteristics were also studied.

A significant association was noted between a high relative humidity exposure and nasal cross-sectional areas (*p*=0.003), and doctor diagnosed allergic rhinitis (*p*=0.002), indicating the presence of allergic rhinitis, as was increased indoor temperature (*p*=0.003). Increased indoor temperature was also associated with increased exhaled nitric oxide (FeNO) (*p*<0.001) indicating uncontrolled asthma. In conclusion, increased classroom temperatures and humidity, both linked to decreased classroom ventilation, were associated with increased incidence of allergic conditions in schoolchildren in Malta. These results emphasize the important need for the introduction of climate control and de-humidifying systems in our schools with the aim of decreasing the prevalence and severity of such conditions in this cohort of patients.

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Background

Several studies on the prevalence of allergic conditions have identified that allergic conditions are on the increase worldwide.[1-3] Therefore, there is ongoing worldwide research to identify possible causative agents so as to be able to provide advice to patients regarding allergen avoidance measures, improvement of environmental and lifestyle factors as well as to individualize treatment accordingly.

Indoor air temperature and humidity levels and their association with allergic conditions, particularly asthma in school-age children, have been investigated in several studies. However, most studies have been performed in households[4-9] and few in classrooms.[10-11] The short-term (0–14 days) health effects of low outdoor temperatures have been well studied in large populations over long time periods. In particular, the association of low outdoor temperatures with respiratory diseases is well established. In these outdoor studies, outdoor temperatures are assumed to be a measure of personal exposure to temperature, but indoor exposure is clearly more important, because people spend a more substantial part of their lifetime indoors,[5] especially children in the classroom. Building construction characteristics have also been studied and identified to have a causal relationship with the development of allergic conditions in children.[12] Furthermore, these results cannot be extrapolated to small island nations like Malta due to the high population density and unique geographical and environmental characteristics.

Objectives

The primary outcome measure of this study was to identify whether indoor classroom temperature and humidity have an impact on the incidence of allergic disease, respiratory symptomatology as well as lung function in primary schoolchildren.

Materials and Methods

Data collection

Five primary state schools in Malta were selected randomly from five geographical clusters of schools designated north (Fgura), south (Birzebbuga), central and urban (Qormi and Fgura), east and close to sea(Pembroke) and west rural(Dingli). Three classrooms within each school were selected among the 9 to 11year age group with all students asked to participate. The classrooms were randomly selected by ballot system so as to eliminate potential bias.

Ethical approval and consent

This study was approved by the University of Malta Research Ethics Committee and the Education Department Research Directorate.

Health assessment and school characterisation

Standardised ISAAC health questionnaires focusing on wheezing, rhinitis and eczema were answered by the children's parents. Lung function tests using a 'microQuark COSMED' handheld portable spirometer, acoustic rhinometry (A1 Acoustic Rhinometer by GM Instruments) , exhaled NO (NIOX MINO), exhaled CO ('piCO+™ CO' monitor) were performed on the participating children. Characterisation of each participating school was performed focusing on the school building, classrooms, cleaning / maintenance protocols and the outdoor environment.

Physical Parameters

Methods of air sampling were based on the International Organisation for Standardisation (ISO) 16000 series [2].[13] CO_2, temperature and humidity were measured continuously using TSI 7525 IAQ-Calc low-cost loggers. Sampling within the schools took place over a five-day period (Monday morning until Friday afternoon) between November and January. Ventilation rates of classrooms were calculated using the indoor and outdoor CO_2 levels.

Statistical Analysis

Data was transferred to IBM SPSS Statistics version 21 (Inc., Chicago, IL) for analysis. For statistical significance, a *p*-value cut off point of 0.05 was adopted. In the case of multiple comparisons, the Bonferroni correction was applied to avoid inflation of the Type 1 error. Regression analysis was used to eliminate any possible confounding factors.

Results

Out of a total number of 237 pupils in all 15 selected classrooms, 191 (80.59%) consented to taking part in the study. The majority of pupils were female (51.16%) while 48.84% were male and the mean age was 9.56 years (SD 0.58).

Up to 32.98% of all the pupils had wheezing at one time in their life (wheezing ever) while 17.8% had current wheezing in the previous 12 months. Up to 16.75% of all pupils actually had doctor-diagnosed asthma. Symptoms suggestive of allergic rhinitis ever were present in nearly 34% of the children while 29.84% of the children complained of rhinitic symptoms in the previous 12 months. Nasal symptoms in the previous 3 months were highly prevalent among the study population with 40% complaining of a runny nose / nasal phlegm, while half of the pupils complained of a blocked nose. Up to 40% of the pupils complained that current rhinitis interfered with their daily activities. Itchy rashes occurring for at least six months were described in 13.61% of the pupils with 65% of them complaining of symptoms in the previous 12 months. Up to 22% of all children participating in the study had a diagnosis of eczema sometime during their life and this was evenly distributed among all schools.

The mean relative humidity within Maltese classrooms was 62.71%. The mean indoor temperature in all five schools was $18.31 \pm 2.23^{0}C$

ranging between a maximum temperature of 22.06^{0}C and a minimum temperature of 14.77^{0}C. The mean 24-hour indoor CO_2 level was 525.21 ppm (SD 300.51 ppm) which is well below the recommended WHO threshold of 1000 ppm (WHO 2010). The mean indoor CO_2 during school hours was 634.32 ppm (SD 201.34ppm). Indoor CO_2 trends showed peak during school hours followed by lower levels when classrooms were unoccupied whilst outdoor CO2 levels were stable (Figure 1). Ventilation rates for each school are shown in (Figure 2). There were significant negative correlations between indoor CO2 concentrations and ventilation rates of the classrooms (r – 0.76 *p* <0.001).

***Figure 1**: Indoor CO_2 levels over 24 hours*

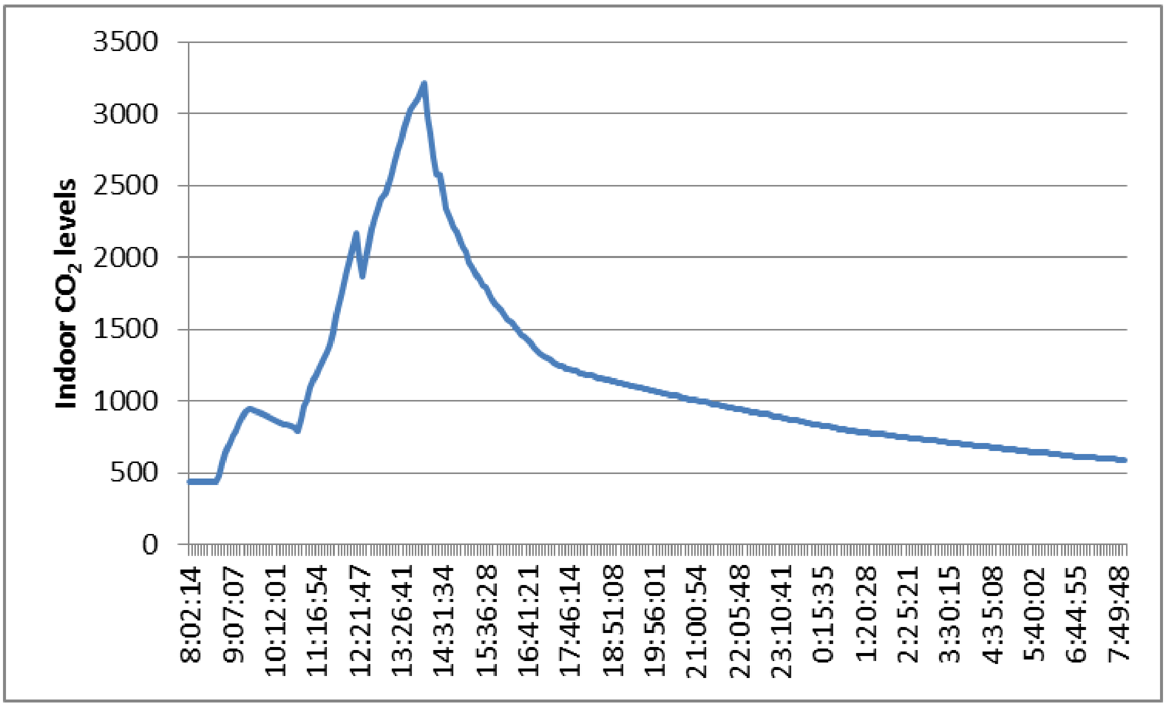
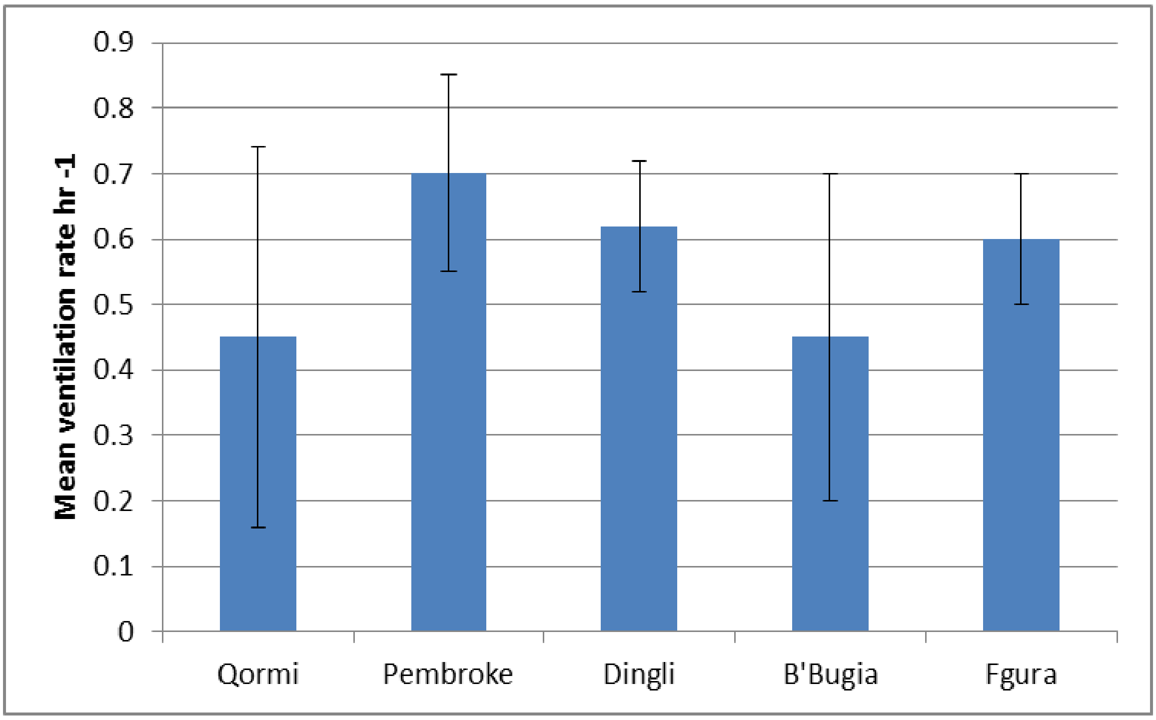


***Figure 2**: Mean indoor ventilation rate per hour*



Association between exposure to environmental parameters and health outcomes

The odds ratios (OR) between symptomatology and environmental exposures was determined by comparing symptoms with high versus low exposure levels to the particular irritant. The high exposure category consisted of pollutant levels equal to or more than the second tertile of concentrations while lower levels of pollutant were defined as low exposure. A logistic regression model was designed so as to eliminate potential confounding factors.

Relative Humidity

Children were less likely to complain of dry throat in the previous three months in classrooms having high humidity levels (OR 0.36, CI 0.14-0.91, *p*=0.027). A significant association was seen between a high relative humidity exposure and nasal cross-sectional areas (*p*=0.003) and exhaled CO (*p*<0.001).

Temperature

Indoor classroom temperatures which were above the third tertile were associated with an increased risk of doctor-diagnosed allergic rhinitis (*p*=0.002, OR 4.83, CI 1.98-7.56). Increased indoor temperature was associated with a decreased nasal mean cross sectional area in both the right and left nostrils on acoustic rhinometry (*p*=0.003; OR 4.69; CI 2.36-7.98) as well as an increased FeNO (*p*<0.001; OR 2.69; CI 1.6-5.65). The mean percentage area of openable class windows was 57%. Class rooms having an openable window area of less than 57% were more likely to have increased indoor temperatures (*p*=<0.001; OR 1.98 CI 1.27-3.68).

Classroom Ventilation

The mean ventilation in the classrooms was 0.56 per hour (SD±0.19; max. 0.88 and min. 0.12). Indoor ventilation was negatively correlated with indoor temperature (r=-0.55; *p*=0.0036), therefore the lower the ventilation the higher the indoor temperature. Children in classrooms having ventilation rates within the lower tertile were more likely to complain of current wheezing (p=0.002; OR 3.44 CI 2.4 – 6.5), itchy rashes in the previous 12 months (OR 3.11, CI 1.1-9.13, p=0.043) and doctor diagnosed atopic eczema (p=0.001; OR 3.64 CI 1.65 – 8.6).

Discussion

Studies dating back to the 1970's recommend guidelines on the implementation of indoor climate requirements and improvement of already existing institutions to improve air quality for school children as well as adult staff members alike.[14]

Humidity

High levels of indoor relative humidity were significantly associated with decreased nasal cross-sectional areas and volumes. No studies have linked rhinitis with increasing temperature although a weak association exists with the prevalence of sinusitis.[15] The local findings might be explained by the fact that warm and / or humid classrooms increased the growth of bacteria and fungi thus potentially increasing the exposure levels to these pollutants.

Indoor relative humidity levels should ideally range between 30 and 70%[16] with the mean humidity level within local schools falling within this range (62.71%). Interestingly, all three classrooms in school 3 (Dingli) exceeded the 70% threshold while all five schools had a relative indoor humidity above the SINPHONIE mean of 43%.[17] The indoor/outdoor ratio for relative humidity (0.88) indicated that the outdoor environment was the major determinant of humidity within local schools. For this reason, one potential limitation to these observations could be the fact that monitoring within all the 5 schools was not simultaneous and therefore meteorological conditions could partly explain the humidity levels detected in school 3 (Dingli) especially since sampling took place in December.

Relative humidity readings quantify the extent of saturation of air by water vapour with January characterized by the highest levels of humidity in the Maltese Islands.[18] Analysis of meteorological data has shown that relative humidity during the winter months plays a major role in thermal comfort both indoors and outdoors.[18] Indoor dehumidifiers within individual classrooms should be considered by school administrators so as to control indoor humidity levels thus improving thermal comfort. This is particularly relevant during winter months where decreasing the indoor humidity levels might reduce the extent of class heating (and energy consumption) needed to achieve acceptable thermal comfort levels.

Temperature

Increasing temperature was found to be significantly associated with doctor-diagnosed nasal allergies in our patients. Higher indoor temperature have been suggested to determine sensitisation and development of atopic diseases.[19] In a study by Mi et al in Shangai, performed on 1414 pupils aged between 13 and 14, current asthma and asthma-related symptoms were associated with indoor temperature. The mean temperature in this study was 17^0C (range 13-21^0C), which compared well with our study.[10] In another study of 1000 random children in Edinburgh, ambient temperature (mean 17.8 ± 1.8^0C) and humidity was recorded in 317 bedrooms but no association was identified with respiratory symptoms.[8] Respiratory tract symptoms have been reported to improve both in frequency and severity during summer holidays and weekends especially among children attending moisture-damaged schools.[20] These studies show that ideally, classrooms should have climate control, , so as to avoid development of allergic conditions.

In addition to increased nasal allergies, indoor temperature was associated with a decreased nasal mean cross sectional area in both nostrils, suggestive of allergic rhinitis, when acoustic rhinometry was performed. Changes in nasal cavity volumes were detected by acoustic rhinometry after exposure to an increase in temperature and humidity in a small study of 8 patients by Lal et al.[21] Acoustic rhinometry is a considered to be a safe, non-invasive, objective, and validated measure of nasal obstruction that appears to be of practical use in the diagnosis and management of inflammatory diseases of the upper airways.[22] Introduction of its use for diagnostic purposes might be useful in Malta in certain cases when diagnostic dilemmas are present.

Exhaled NO levels were also raised in association with increased temperatures, suggesting increased airway inflammation. In contrast to our study, Pierse et al identified that a 1^0C increase in temperature (mean bedroom temperature 14.4°C, mean living room temperature 16.53°C.) was associated with a slight overall improvement in lung function, measured using spirometry and peak flow. Exhaled NO was not performed in this study.[5] The effect of temperature on lung function seems to be inconsistent. The prevalence of wheezing in school children was lower in classrooms having higher temperatures,[23] however children were more likely to complain of breathlessness.[10]

Pollutants

Human beings are the main source of indoor CO_2 since they exhale carbon dioxide as a byproduct of metabolism with the average adult's breath having between 35,000 to 50,000 ppm of CO_2.[24] The American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) recommends using indoor CO_2 levels to determine the ventilation characteristics of the building. Furthermore, ASHRAE recommends that the mean indoor CO_2 level should not exceed outdoor CO_2 concentrations by more than about 600 ppm.[24] Mean indoor CO_2 levels were below both the recommended WHO threshold of 1000 ppm[25]. A significant negative correlation was found between indoor CO_2 concentration and ventilation rates of the classrooms, confirming usefulness of CO_2 monitoring as a marker of indoor ventilation characteristics.

The characteristics of indoor homes from 280 elementary school students in Romania have also been implicated to cause increased respiratory symptoms in a recent study as part of the SINPHONIE project,[9] related to the limited use of indoor climate control.[9] It has been reported that schools frequently have trouble maintaining indoor relative humidity within the optimum range (30-50 %) recommended for reducing allergens and irritants.[26] Building characteristics have been studied[10,12] and found to contribute to respiratory morbidity with worsened symptoms.[12] Classroom windows of studied schools in Malta could only be half opened. As expected, this resulted in higher indoor temperatures since climate control was not available for use in any of the studied schools. Independently, decreased ventilation was associated with a significant increase in the risk of current wheezing and itchy rashes in the past 12 months as well as an increased risk of doctor-diagnosed atopic eczema. Asthma symptoms are known to be influenced by lack of ventilation in Shangai.[10] Unventilated indoor climate is associated with increased prevalence of asthma, allergic rhinitis and eczema in schoolchildren.[27] Opening windows results in outdoor environmental air pollutants as well as outdoor aeroallergens such as tree and grass pollen entering the classroom. However, closed windows means that indoor allergens such as house dust mite, animal dander and mould spores are not able to exit the room. When measured, cat and dog allergens were found to be very high in schools,[28] which must be carried on childrens' and staff clothing, emphasizing the need for frequent school cleaning. Sensitisation to indoor allergens has been identified as a major risk factor for the development of childhood asthma several years ago.[19] This is a reasonable finding, particularly in the westernized world since children tend to spend several hours during the day indoors either in their home or in a classroom. House dust mite and mould are determined by their microenvironments. Humidity and warm temperatures tend to favour their growth.[29,30] Single allergens, increased humidity and visible moulds were significantly associated with house dust mite and mugwort pollen.[31] Indoor moulds have been studied in some international studies, to identify whether mould exposure may be linked to childhood respiratory disease. However Celtic identified that mould was not a predisposing factor.[32] In contrast, Yazicioglu et al did identify that fungal counts were higher in the homes of asthmatic children whilst Mi et al observed that indoor moulds were associated with increased asthma exacerbations.[10] Window opening has been described as the only way to remove indoor pollutants.[10] Cooler temperatures could also allow bacteria and viruses to thrive less and result in a reduction in respiratory tract infections.

From our study we can say that it is more advantageous for outside pollutants to enter whilst allowing indoor allergens to exit, but this obviously depends on the surrounding environment where the schools are located. One must keep in mind that elevated levels of air pollutants have also been reported in several studies to be detrimental to respiratory health.[33-35]

Similar studies have also been extrapolated to study teachers, who have been identified to have a higher asthma prevalence than other non-industrial worker groups. Classroom humidity and teachers' respiratory health was explored in North Carolina. Though statistical significance was not reached, there was a modest increase in the risk of respiratory symptoms.[26]

Limitations

The main limitation of the present study is the relatively small number of children participating. CO_2 data interpretations might result in the overestimation of ventilation rates. Investigations for sensitization to aeroallergens, such as dog and cat dander, house dust mite and moulds, would be ideal to complement our findings, since positive results would explain the increased prevalence of allergic conditions in our cohort. Measurement of outdoor pollutants and correlation with ventilation and respiratory symptoms could also provide an explanation to our findings. Fungal counts were not measured in our study.

Conclusion

Higher classroom temperatures and humidity, linked to decreased ventilation, were associated with increased incidence of allergic rhinitis symptoms together with narrowed nasal passages, worsened asthma control and increased atopic eczema. Schools should be advised that classrooms should be well-ventilated, windows opened regularly, possible introduction of mechanical ventilation and dehumidification with the aim of decreasing allergy-associated symptomatology and conditions in children, who spend a significant amount of their childhood years in such an environment. Humidity levels and temperatures should be kept low. Despite our associations, one must keep in mind that causation of allergic conditions is multifactorial, and must be studied on an individual basis.

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