Are Environmental Conditions in South African Classrooms Conducive for Learning?

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Abstract:
Environmental factors have been shown to have a significant impact on quality of education. This exploratory study investigates environmental conditions in a case study classroom at a South African secondary school. It undertakes field measurements within a classroom over a typical school day in summer. Measurement data from the study is analysed and interpreted in relation to indoor environmental condition standards developed by American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE) and South African Bureau of Standards (SABS).

The study indicates that environmental conditions in the case study classroom do not achieve the environmental standards defined by ASHRAE and SABS. This suggests that the classroom does not provide an environment that promotes productivity and comfort for particular summer conditions, and therefore is unlikely to be conducive for learning. The paper draws a number of conclusions from the study and makes recommendations for further research.

Keywords: Assessment, Environmental Conditions, Schools

1 Introduction

Existing studies show a direct link between physical environment in which learners are taught, learning effectiveness and student learning outcomes (Schneider 2002, Seppänen et al. 2006) Poor learning environments have been found to contribute to irregular student attendance and dropping out of school and teachers' absenteeism and ability to engage in the teaching and learning process (Haverinen-Shaughnessy et al. 2011).

Indoor Environmental Quality (IEQ) factors such as extreme thermal conditions have been found to increase irritability and reduce students' attention span and mental efficiency. This results in an increased rate of students' errors, teacher fatigue and deterioration in work patterns (Jago and Tanner 1999, Schneider 2002). Good lighting has been found to improve students' ability to perceive visual stimuli and their ability to concentrate on instruction (Schneider 2002).

This paper describes an exploratory study of environment conditions within a case study classroom in order to establish whether environment conditions in classrooms are conducive to comfort, productivity and learning. The main research question addressed by the study is:

- Do South African school classroom indoor environments, as represented by the case study, achieve indoor environmental quality standards as outlined by legislation and good practice standards?

This question is answered by addressing the following sub-questions:

- What standards define acceptable, or minimum, environment conditions in class rooms?
- How does a case study classroom perform in relation to minimum and good practice indoor environmental control standards in learning environments?

The paper describes an exploratory study of environmental conditions in a class room as a pilot for a larger-scale assessment process. It is acknowledged that a larger-scale survey is required in order to increase the validity and significance of findings for this type of study.

2 Minimum Environmental Conditions

There are a range of different standards that can be used to define acceptable, or minimum, environmental conditions for classroom, such as those developed by the World Health Organisation. In this exploratory study environmental conditions assessed will be restricted to lighting, indoor air quality and temperature. Reference standards for these aspects are drawn from South African building regulations for lighting requirements and the American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE) standards, for thermal and indoor air quality requirements. These are outlined in table 1.

Table 1. Minimum environmental conditions.

Aspect	**Reference**	**Acceptable / minimum standards**
Light	National Building Regulation and Building Standards (South Africa)	Above 200 lux on working surfaces.
Indoor air quality	Upper control limit concentration (Caution Level) based on 400ppm ambient and ANSI/ASHRAE Standard 62.1-2007: Ventilation for Acceptable Indoor Air Quality in Low-Rise Residential Buildings ASHRAE (ASHRAE 2007, Lawrence 2007)	CO2 concentrations below 942 ppm.
Temperature	ANSI/ASHRAE Standard 55-2004 Thermal Environmental Conditions	25.0°C to 28.0°C (at 0.5 Clo, 20% RH)

	for Human Occupancy (ASHRAE 2004).	

3 Case Study

The classroom selected is representative of standard classrooms in public schools in South Africa. The building is approximately 20 years old and is located in Attridgeville, a township in Pretoria, South Africa (latitude -25.7733, longitude 28.0713). The physical properties and occupation of the classroom is described below.

Physical properties

The case study classroom has the following physical characteristics:

- The classroom is within in a linear, single storey block consisting of 4 classrooms.
- The building envelope is composed of face brick walls with fenestration on North and South walls and double pitched corrugated steel roof with a plasterboard ceiling.
- The internal walls of classrooms are composed of face brick from the floor level to 1100mm above finished floor level. Above this walls are finished in plaster and paint to the ceiling.
- The North side of the block is characterised by centre pivot steel windows school at 1568mm above finished floor level. The openable area of one window is $0.84m^2$.
- The South facing side of classroom block is characterised by a row of 1303mm x 1445 mm steel school window, with top and bottom openable areas with the top window pivot having an openable area of 1.17 m2 (1303mmx978mm) and bottom hung window with an openable area of 0.6 m2 (1303mmx467mm). The lower section of these windows are all painted with dark green paint, to limit views and therefore distractions.
- The classroom area size is 52.78 m^2 (7440 mm x 7560mm).
- A plan of the classroom and furniture layouts is provided in figures 1 and 2. Plans are orientated with North to the top of the page

Occupation

The occupation schedule of the classroom is as follows:

- The classroom was occupied by 44 learners throughout the morning. An educator was present for most of the morning.
- Classes within the space are scheduled 08:00 to 13:30 with a 30 minutes break from 11:00-11:30.

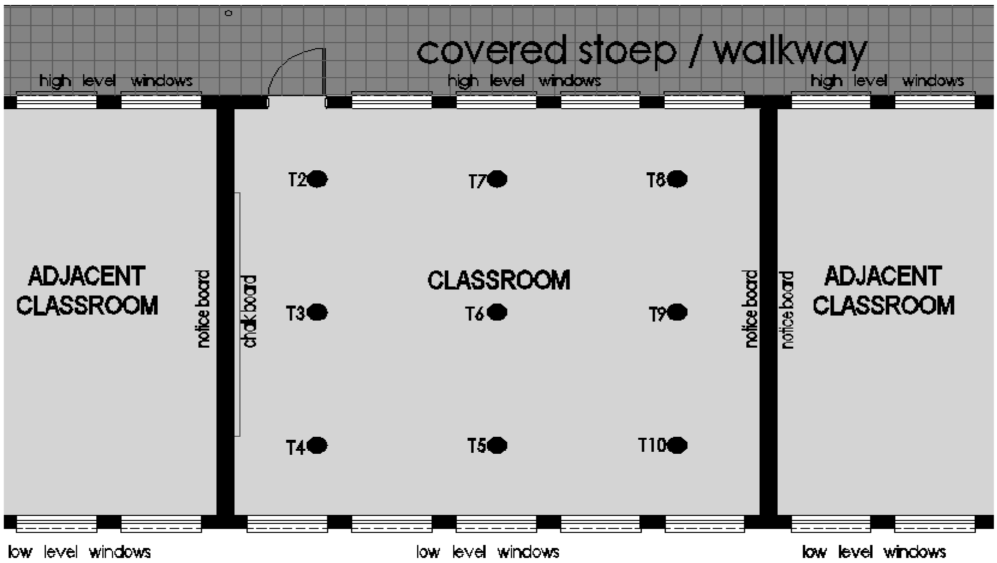

Figure 1. The location of category T2-T10 measurement locations (T1 is taken externally in the quad/assembly area).

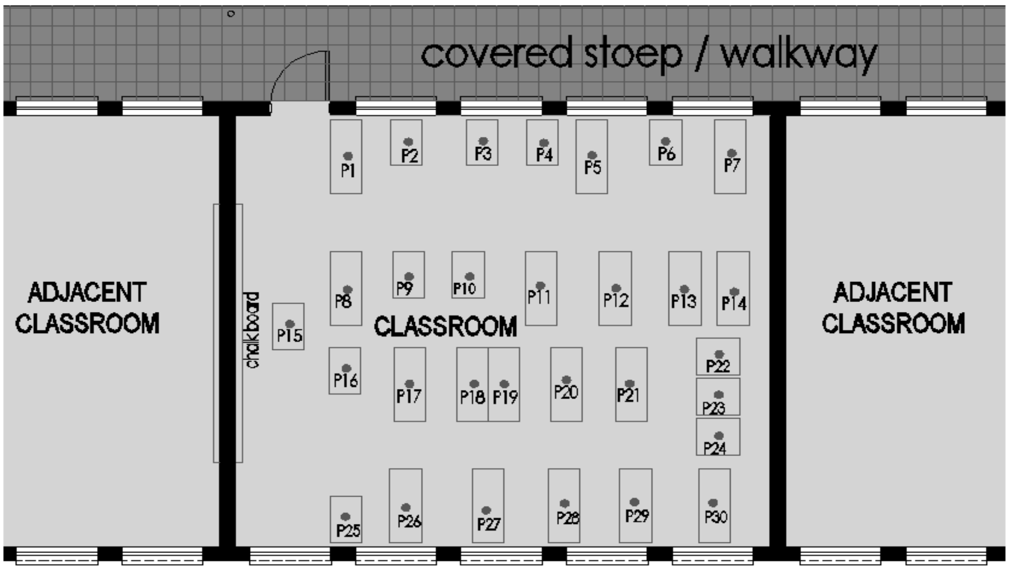

Figure 2. The location of category P1-P30 measurement locations.

4 Methodology

In order to obtain data on both the performance of the building and the experience of occupants, two types of measurements were taken.

Type 'T' measurements are designed to reflect building performance and are measurements of environmental conditions at uniform locations within the classroom, as indicated in Figure 1. The external T measurement (T1) was measured at the centre of the external quad/assembly area and the internal T points (T2-T10) are positioned 1200mm away from the 4 internal classroom walls and +/- 2581mm away from each other. T measurements were taken every hour from 8:30 - 13:15, with measurements being completed within a 15 minute period. ‘T’ locations were marked on the floor of the classroom to ensure consistent measurement locations.

Type ‘P’ measurements are designed to reflect the actual experience of occupants in the classroom. These measurements were taken at the desk locations of occupants as indicated by locations ‘P’ in figure 2. There are 30 desks in the classroom and 28 of these were occupied. The number of occupants at each desk varies from 1 to 4 students. The desks are marked and tagged P1 – P30 and measurements were taken once, at 13:30, within a period of 15 minutes.

Instrumentation used including a digital lux meter, a CO2 meter and a digital thermocouple (Sentry ST 303 multimeter). Measurement processes aligned with ASHRAE protocols and included the following aspects (ASHRAE 2004).

- Lighting was measured at 730mm above finished floor level at the marked locations.
- Carbon dioxide was measured at 1100mm above finished floor level at the marked locations.
- Temperature was measured at 1100mm above finished floor level at the marked locations.

5 Findings

5.1 Lighting

Figure 3 below shows lighting levels in the classroom for different T locations over the morning (08:30 – 13:30).

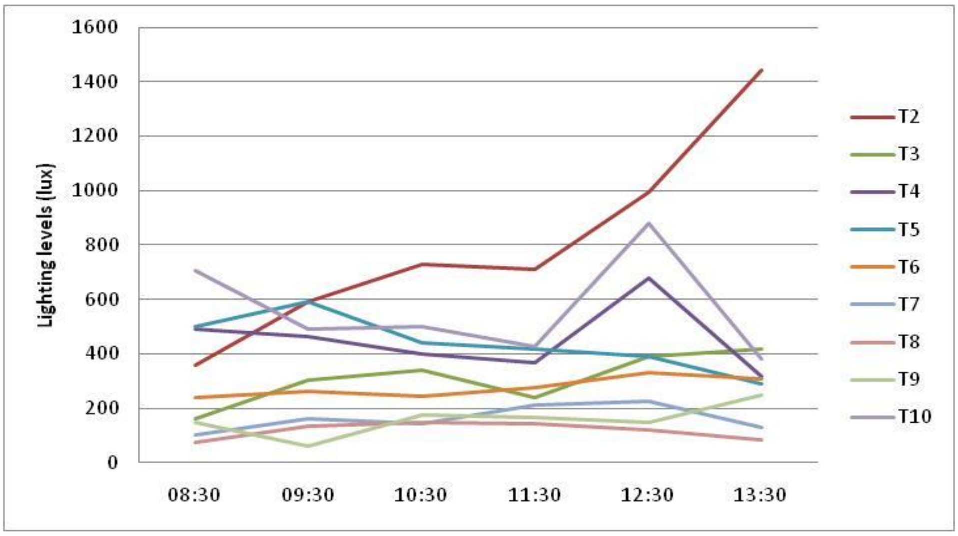

Figure 3. Lighting levels for different T locations in the classroom over a morning.

Lighting levels for most locations reduce after 12.30. This is probably due to reduced external lighting levels as a result of cloud cover. The figure shows that a number of locations (T2, T7, T4, T5) had consistent lighting levels of above 400 lux, other locations (T6, T3) were just above the minimum requirement of 200lux. It also shows that a number of locations (T8, T9, T10) where consistently below the minimum requirement of 200lux.

Figure 4 below shows lighting levels in the classroom for different desk (P) at 13:15.

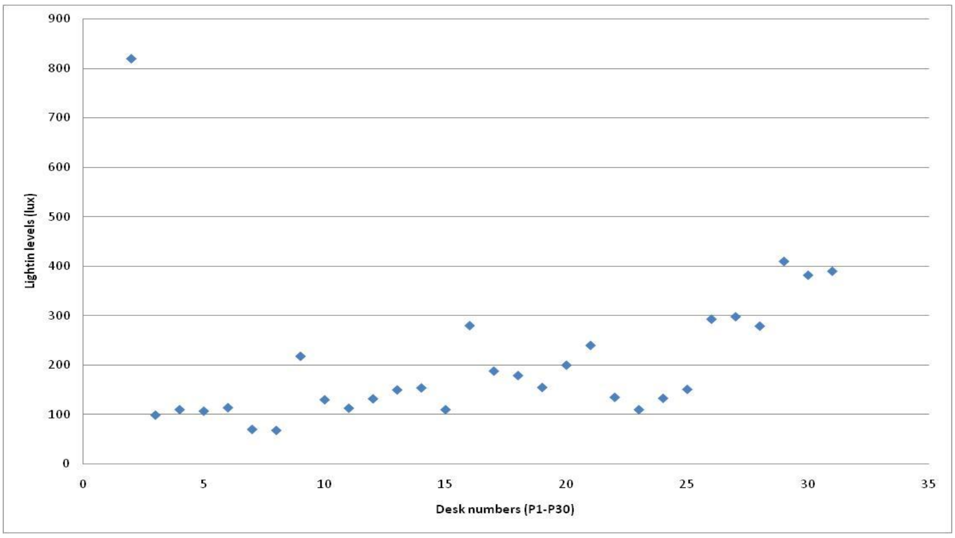

Figure 4. Lighting levels for different desks (P) at 13:15.

Figure 4 shows that 19 desks (63%) have lighting levels under 200lux and 11 desks (39%) have lighting levels of above 200lux. This shows that 63% of desk light levels that are below the minimum lighting standard of 200lux.

The figure also shows that only one row of desks in the classroom (row P25-P30) receive above 200lux. These desks are adjacent to the low levels windows. Desks adjacent to the high level windows (P2 –P7) all receive less than 200lux. Desks in the centre of the classroom (P8 – P24) also appear to generally have less than 200lux. Desk locations P9 and P16 have higher lighting levels than the rest of the desks in the centre of the classroom. This is probably due to light from the door. Desk location P1 has very high light levels (800lux) as this is beside the open door.

There are number of interesting findings in relation to lighting in the classroom that can be discussed.

Lighting levels: The results show that lighting levels in some areas of the classroom are below the minimum of 200lux. As good lighting levels are required to write and read, it is possible that poor lighting levels are negatively affecting the quality of learning and should be addressed immediately.

Lighting levels near the door: Figure 17 and 18 shows that lighting levels near the door (T2) are lower than lighting levels near windows early in the morning. They then rise above lighting levels near windows and carry on rising even after lighting levels near windows appear to drop due to cloud cover. This can probably be explained by the fact that lighting near the door has a higher reflected component received from lighting reflected from the walkway. This reflected component is proportionally lower in the early morning when sun angles are low and appears to be only marginally affected by reduced sunlight intensity later in day.

This suggests the following further investigations should be carried out.

- *Is there the potential to improve day lighting, both in intensity and consistency in classrooms through greater use of reflected light?*
- *Can surfaces, such as light coloured walkways adjacent to classroom be used to reflect light into classrooms?*
- *Would a light shelf connected to walkway columns be effective in increasing reflected light into the classroom through high level windows?*

Lighting levels and the location and size of windows: Figure 3 and 4 show that the high level windows do not contribute to lighting in the classrooms. This is probably due to the fact that these are located where they receive limited light from the sky as they are immediately underneath the roof so are shaded and receive limited reflected light from the walkway. The low level windows on the North provide light to desks immediately beside them, but are not effective at distributing light further into the classroom. This suggests the following further investigations should be carried out.

- *Can lighting in classrooms be improved by providing lower level windows on the North façade of classrooms?*
- *Would locating walkways on the South side of classrooms improve lighting by reducing the extent to which North light is reduced by the roof?*

5.2 Air quality

Figure 5 below shows carbon dioxide levels in the classroom relative to external carbon dioxide levels over a morning (08:30 – 13:30). T1 indicates external lighting levels and T2-T10 indicate lighting levels within the classroom.

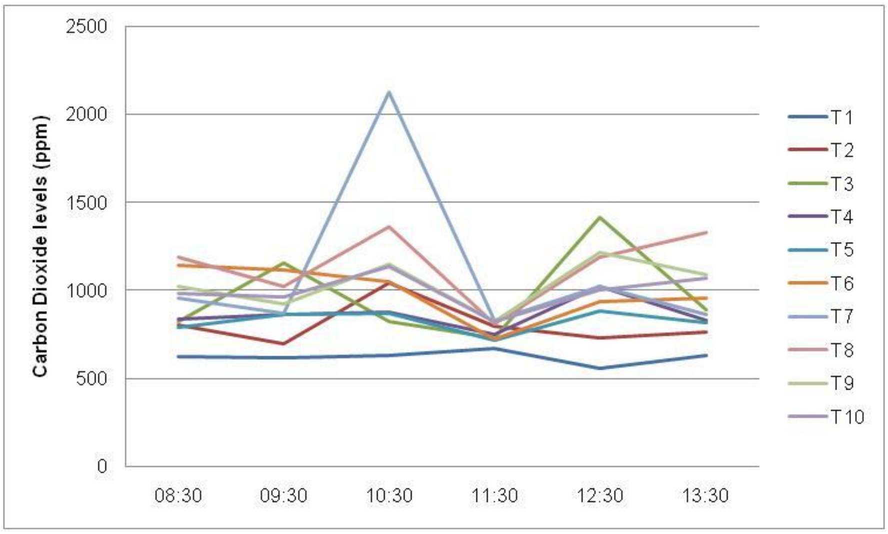

Figure 5. Carbon dioxide levels for different locations (T2-T10) in the classroom over a morning relative external carbon dioxide levels (T1).

Figure 5 shows that carbon dioxide levels in the classroom generally remain at the same level over the morning, within a band of about 750-1250ppm. Carbon dioxide levels at all locations in the classroom drop at 11.30 in the morning. This is likely to be due to break-time when most learners leave the classroom. One location (T7) experiences significantly higher carbon dioxide levels at 10:30 than other points in the classroom. This location is near the high level windows and has a high density of learners. The higher levels experienced are probably due to poor airflow and the higher learner density at that particular location.

Figure 6 below shows carbon dioxide levels in the classroom for different desks at 13.15.

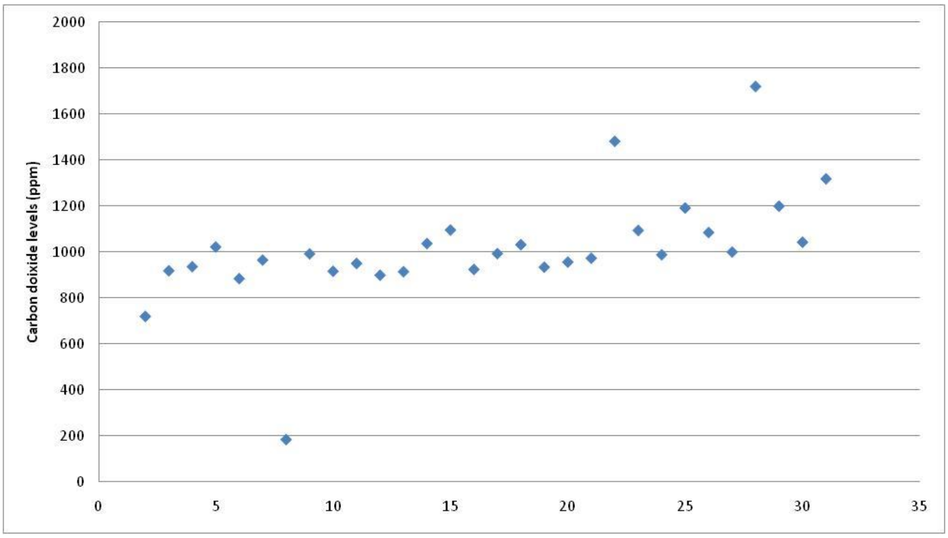

Figure 6. Carbon dioxide levels for different desks at 13:15.

Figure 6 shows that most locations in the classroom at 13:15 have carbon dioxide levels of about 1000ppm. There are however locations where levels are over 1500ppm, which is well in excess of the limits suggested by the Standard (ASHRAE 2007).

There are number of interesting findings in relation to carbon dioxide levels in the classroom that can be discussed.

Carbon dioxide levels: Carbon dioxide levels do not increase over the morning despite the high density of learners in the classroom. This suggests that levels of ventilation and infiltration in the classroom allow some dilution of carbon dioxide levels above concentrations of about 1250ppm.

Breaks: Carbon dioxide levels in all locations in the classroom dropped over the break period when most learners left the classroom. This indicates that ventilation at this time helped to flush the classroom with fresh air and reduce background carbon dioxide levels.

This suggests the following further investigations should be carried out.

- *Do breaks play a significant role in reducing carbon dioxide levels in classrooms?*
- *Would it be better for learners to move between classrooms for different lessons enabling stale air to be flushed out of classrooms during this movement and the 5-10 minute unoccupied period?*

5.3 Temperature

Figure 7 below shows air temperature in the classroom relative to external temperatures over a morning (08:30 – 13:30). T1 indicates external temperature levels and T2-T10 indicate classroom temperatures within the classroom.

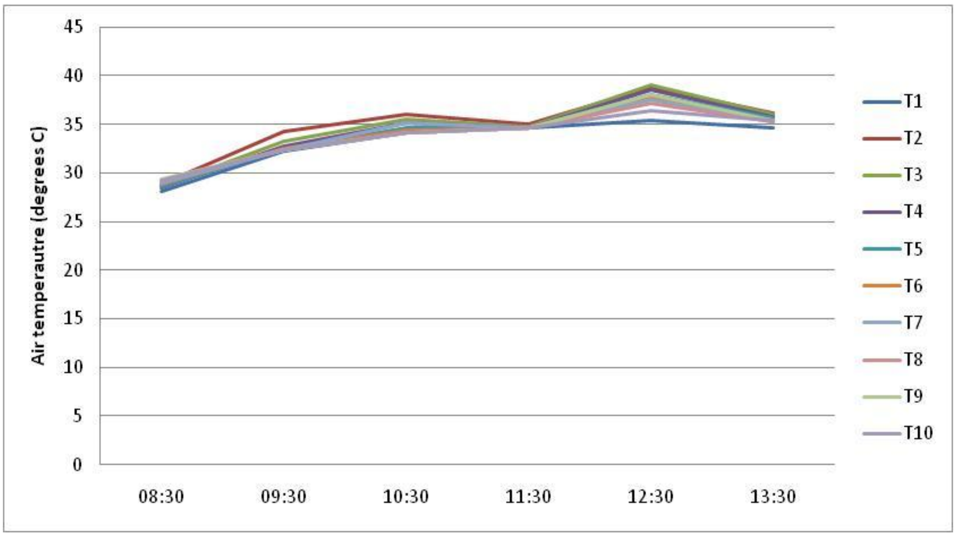

Figure 7. Air temperatures at different locations (T2-T10) in the classroom over a morning.

The figure shows that there is very little difference between external air temperatures (T1) and internal classroom temperatures (T2-T10).

Figure 7 shows that temperatures increase over the morning from about 28 degrees C to a peak of 38 degrees C at 12:30 with temperatures dropping to about 35 degrees at 13:30. This shows that temperatures were well over the maximum temperature of 28 degrees C for entire morning. Temperature increases level off at 11:30. This may be due to the break period when most learners leave the classroom and therefore reduce the heat load. Temperatures drop again at about 12:30 which may be due to cloud cover and reduced heat conduction through the roof.

Figure 8 below shows air temperatures for different desks at 13:15.

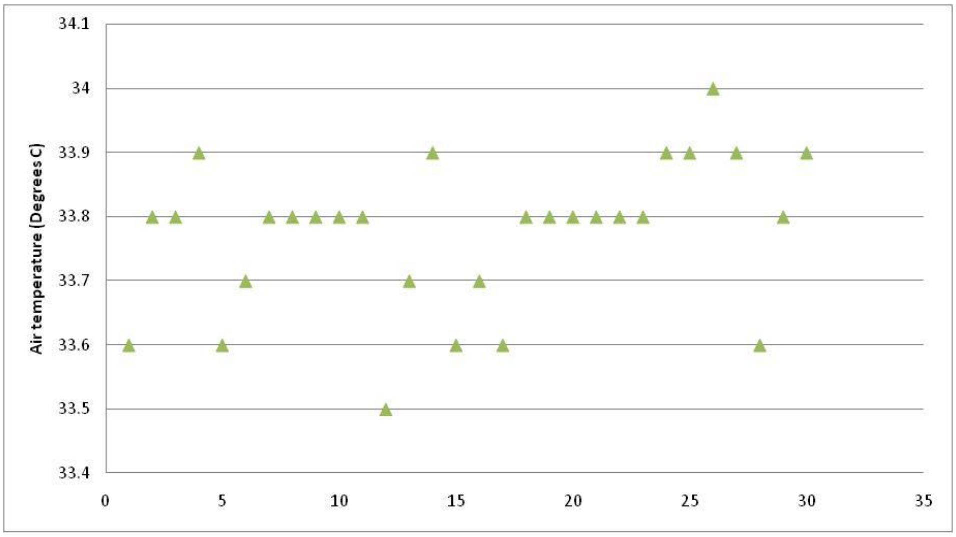

Figure 8. Air temperatures at desks at 13:15

Figure 8 shows that temperatures at desks are between 33.5 and 34 degrees C. This indicates that all desk locations experience temperatures in excess of the maximum air temperature detailed in the ASHRAE standard for thermal environmental conditions (ASHRAE 2004).

There are number of interesting findings in relation to temperature in the classroom that can be discussed.

Environment control: The results show that the classroom is ineffective at thermal environmental control. Indoor air temperature track ambient air temperatures closely and the building envelope appears to play no role in making thermal environments within the class room more comfortable.

Temperature increases: Air temperature increases in the classroom are probably due to a combination of warmer air entering the classroom from outside, solar heat gain through the roof and the heat load from occupants. This finding is confirmed by the air temperature drop experienced at about 11:30 when cloud cover results in reduced solar heat gain and a break reduces heat loads from occupants. This suggests the following further investigations should be carried out.

- *Insulation in the roof could help reduce temperature increases in the classroom by reducing heat being conducted through the roof.*
- *Temperature increases from occupants could be reduced by having regular breaks between lessons to enable classrooms to be vacated of learners and be flushed with fresh cooler air.*
- *It may be possible to use diurnal range to keep classrooms cool. This would require increased thermal mass in the classroom which would be exposed to cool night air to cool down. Cooled thermal mass would then act as a heat sink during the day limiting increases in internal temperatures.*

6 Conclusions and Recommendations

The study shows that internal environmental conditions in the case study classroom do not comply with SABS and ASHRAE standards for occupant comfort and productivity. Therefore, the paper concludes that the case study classroom building does not provide environmental conditions conducive for learning in particular summer conditions.

Further research should be carried out to establish how prevalent these types of conditions are in classrooms and how representative the case study classroom is of other classroom buildings in South Africa. This research should take into account local variations in climate and teaching practice.

In addition, research should be undertaken to identify, and test, interventions that can be used to improve environmental conditions in classrooms and ensure that these are compliant with SABS and ASHRAE standards. Recommended areas for investigation include:

- **Roof insulation:** Data from the case study indicates that internal temperature increases may be due in part from heat gain through the corrugated metal roof. Roof insulation could counter this heat gain to reduce internal air temperatures. Roof insulation and the roof colour may therefore be valuable factors to investigate.
- **Management:** Data from the case study indicates that the break when students left the classroom may have resulted in increased fresh air within the classroom. This may help to reduce carbon dioxide levels and reduce air temperatures. Therefore class timetabling and space scheduling may be a valuable non-capital intensive avenue to explore in improving environmental conditions.
- **Windows and light shelves:** Lighting data indicates that light shelves and / or larger windows on the north face of the building are likely to improve internal lighting conditions. These interventions could be modelled with lighting software as a means of improving lighting levels in a classroom.

Finally, it is recommended that research in this area inform the development of school classroom design guidelines. In particular, these should ensure that design fundamentals such as building form and orientation, the location of corridor access, envelope insulation values, fenestration location and size and ventilation opening size respond to local climates and school management schedules to create conducive environments for learning.

7 References

ASHRAE (2004), 'ANSI/ASHRAE Standard 55-2004: Thermal Environmental Conditions for Human Occupancy', American Society for Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA.

ASHRAE (2007), 'ANSI/ASHRAE Standard 62.1-2007: Ventilation for

Acceptable Indoor Air Quality in Low-Rise Residential Buildings', American Society for Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA.
Haverinen-Shaughnessy, U., Moschandreas, D., Shaughnessy, R., (2011), 'Association between Sub-Standard Classroom Ventilation Rates and Students', Academic Achievement. Indoor Air, 21(2), pp. 121–131.
Jago, E, and Tanner, K., (1999), 'Influence of the School Facility on Student Achievement', University of Georgia. Website: http://www.coe.uga.edu/sdpl/researchabstracts/thermal.html Accessed 29/11/11.
Lawrence, T., (2008), 'Selecting Outdoor CO2 Criteria for Outdoor Air Monitoring', ASHRAE Journal, December 2008, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc
Schneider, M, (2002), Do School Facilities Affect Academic Outcomes? National Clearinghouse for Educational Facilities, National Institute of Building Science, November 2002.
Seppänen, O., Fisk WJ, Lei Q.,H., (2006) Ventilation and performance in office work, Indoor Air, 16(1), pp. 28-36.