The development and critical evaluation of learner thermal comfort protocol for applicability to two primary schools in Mamelodi, City of Tshwane

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THESIS SUMMARY

The development and critical evaluation of learner thermal comfort protocol for applicability to two primary schools in Mamelodi, City of Tshwane

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To my parents

Kgosi Mokalake Motsatsi II and Kgosigadi Dikolo Motsatsi

Ke a leboga Batlokwa!

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Father, God almighty, without you I never would have made it. I thank you for your guidance and the lessons learnt throughout this journey. I now know that this journey's purpose was to bring me closer to you!

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Abstract

The purpose of this study is to develop a Learner Thermal Comfort Protocol (LTCP) for the assessment of thermal comfort in naturally ventilated public school classrooms occupied by primary learners aged between 7 and 14 years and to establish whether there is a relationship between the thermal comfort standards (ASHRAE 55-2004 and ISO 7730-2005) and the learners' perception thereof.

The study tests the LTCP on two primary school case studies in Mamelodi Township, City of Tshwane (CoT), South Africa, by following the adaptive or field study method to collect quantitative data from the classroom and the learners. The classrooms' actual temperature is measured and recorded by HOBO pendant data loggers while the learners' thermal comfort perception is surveyed using questionnaires. The actual classroom indoor temperatures are compared to the ASHRAE 55 and ISO 7730 standard temperature range recommendations of ±22°C to ±27°C, based on the heat balance model, and ±20°C to ±27°C temperature range based on the context related adaptive model. To establish whether there is a relationship between standards and learners' perception, the learners' perception results are compared to the predicted percentage that occupants would find acceptable. This predicted percentage is based on the heat balance model (i.e. 80%) and adaptive model (i.e. 80% - 90%).

The results indicate that the indoor temperature range did not meet the recommended temperature range of either of the thermal comfort models. However, the thermal perception scale shows that the indoor temperatures were accepted by most of the learners. A relationship between the learners' perception, the thermal comfort standards' recommended temperature range and predicted percentage of acceptance was established. However, a wider temperature range is suggested for the thermal comfort assessment of classrooms located in the South African climate.

This study will contribute to the body of knowledge on thermal comfort in schools and provide the Department of Basic Education (DBE) with an assessment tool for the evaluation of school classroom indoor environments.

Key words: Thermal comfort, ASHRAE 55 standard, ISO 7730 standard, primary school, Mamelodi Township, adaptive model, Learner Thermal Comfort Protocol.

Abstrak

Die doel van hierdie studie is om 'n Leerder Termiese Gemaksprotokol (Learner Thermal Comfort Protocol (LTCP)) te ontwikkel vir die assessering van termiese gemak in natuurlik-geventileerde openbare skoolklaskamers wat gebruik word deur primêre leerders tussen 7 en 14 jaar oud en om te bepaal of daar 'n verwantskap is tussen die ASHRAE 55-2004 en ISO 7730-2005 termiese gemakstandaarde en die leerders se persepsie daarvan.

Die navorsing toets die LTCP op twee gevallestudies in Mamelodi in die Stad Tshwane, Suid-Afrika deur die bepaling van die proefpersone se persepsuele realiteit met behulp van veldwerk om kwantitatiewe data van die klaskamers en vanaf die leerders te verkry.

Die klaskamers se werklike temperatuur word gemeet en aangeteken deur HOBO datavasleggers en die leerders se persepsie oor hul termiese gemak word opgeneem deur vraelyste. Die werklike gemete temperatuur in die klaskamers word vergelyk met die ASHRAE 55-2004 en ISO 7730-2005 standaarde se aanbevole temperatuurreeks van ±22°C to ±27°C wat gebaseer is op die hitte-balansmodel asook op die ±20°C to ±27°C temperatuurreeks gebaseer op die konteksverwante aanpassingsmodel. Om te bepaal of daar 'n verwantskap is tussen die genoemde standaarde en leerderpersepsies, word laasgenoemde se bevindings vergelyk met die voorspelde persentasie wat bewoners sal aanvaar. Hierdie voorspelde persentasie word baseer op die hitte-balansmodel se 80% en die konteksverwante aanpassingsmodel se 80% - 90%.

Die bevindings dui daarop dat die gemete binneshuise temperatuurreeks nie die aanbevole temperatuurreeks van beide termiese gemaksmodelle bevredig nie. Nieteenstaande hiervan dui die termiese persepsieskaal daarop dat die binneshuise temperature deur meeste leerders aanvaar word. 'n Verwantskap tussen leerderpersepsies, die termiese gemakstandaarde se aanbevole temperatuurreeks en die voorspelde aanvaarbaarheidpersentasie is bepaal. Desondanks word 'n wyer temperatuurreeks voorgestel vir die assessering van termiese gemak van klaskamers vir die Suid-Afrikanse klimaat.

Hierdie studie dra by tot die kennisveld oor termiese gemak in skole en voorsien die Departement van Basiese Onderwys van 'n assesseringinstrument vir die evaluering van skoolklaskamers se binneshuise omgewings.

Sleutelwoorde: Termiese gemak, ASHRAE 55 standaard, ISO 7730 standaard, primêre skool, Mamelodi woongebied, konteksverwante aanpassingsmodel, Leerder termiese gemaksprotokol.

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Declaration

1. I understand what plagiarism entails and am aware of the University's policy in this regard.
2. I declare that this dissertation is my own, original work. Where someone else's work was used (whether from a printed source, the internet or any other source) due acknowledgement was given and reference was made according to departmental requirements.
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Handtekening ________________________________

1 Introduction

1.1 The problem and its context

Comfortable temperatures are important for keeping the human body at a constant internal core temperature of about 37.0°C and failure to avoid fluctuations can lead to ill-health (Nicol, Humphreys & Roaf 2012, Parsons 1993). The aged, the sick and children are most sensitive to thermal discomfort. In particular, children when compared to adults are more susceptible to extreme temperatures because of their unique physiology, such as less developed thermoregulatory systems and higher metabolic rates that may render them more sensitive to heat (Xu, Perry, Sheffield, Su, Wang, Bi, & Tong 2013). Children are also vulnerable in environments that they cannot adapt or control when feeling thermally uncomfortable, such as opening or closing windows (Wigle 2003).

Therefore, thermal comfort consideration of spaces in which children spend much of their time, such as school classrooms is important. School classrooms can have high occupant densities that may result in unsatisfactory thermal environments in the summer time if thermal comfort is not considered in building design (Zhang, Zheng,Yang, Zhang & Moschandreasa 2007).

Thermal discomfort in classrooms has been found to have a negative impact on learners' performance. Physiological and psychological responses such as increased irritability, as well as reduced attention span and mental efficacy may result in an increased rate of learner errors, teacher fatigue and deterioration of work patterns (Jago & Tanner 1999, Humphreys 1973, Parsons 1993, Schneider 2002).

An acceptable summer indoor operative air temperature range for naturally ventilated school buildings is recommended to not exceed 25.0°C, and an indoor operative air temperature above 28.0°C is limited to 1% of the annual occupied period (Chartered Institution of Building Services Engineers (CIBSE) 2006).

An ambient air temperature between 25.0 ºC and 28.0 ºC may result in learners' feeling hot and uncomfortable resulting in lower productivity levels. Indoor operative temperatures that stay at or over 28.0 ºC for long periods of the day will result in dissatisfaction for many occupants (CIBSE 2006).

The ISO 7730-2005 Standard specifies categories of buildings according to the range of Predicted Mean Vote (PMV) that occurs within them. School classrooms are categorised by the categories "A/B/C", meaning that when the classroom is categorised as 'category A' it maintains its indoor thermal comfort environment within ±0.2 PMV (Predicted Percentage Dissatisfied (PPD) ≤ 6%), under 'category B' it maintains its indoor thermal comfort environment within ±0.5 PMV(PPD ≤ 10%), 'category C' maintains its indoor thermal comfort environment within ±0.7 PMV(PPD ≤ 15%) provided that the learners' activity level produces heat of 70 Watt per square metre (W/m^2) for all categories; yet clothing insulation and air temperature differ for all the categories (see tables 3 & 4).

For example, category 'C' maintains the indoor thermal comfort environment within ±0.7 PMV/PPD ≤ 15%. Therefore, in this category ISO 7730-2005 predicts that the school classroom will be thermally acceptable to about 85% of the occupants when the building is slightly warm while about 15% of occupants will be dissatisfied with the environment. Eighty-five percent (85%) of occupants will be satisfied with the thermal environment on the condition that their activity level produces heat of $70W/m^2$ (seated, metabolic rate at about 1 met); their clothing insulation is valued at $0.5I_{cl}$ in summer and the surrounding temperature is within a range of ±2.5°C above or below **24.5°C** (i.e. 22°C - 27°C) and air velocity is 0.24m/s. In winter, the occupants' clothing insulation must be valued at $1I_{cl}$, with temperatures within a range of ±3°C above or below **22.0°C** (i.e. 19.0°C - 25°C) and air velocity at 0.21m/s (ISO 7730-2005, Parsons 1993).

On the other hand, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Adaptive Thermal Comfort Standard 55 for naturally conditioned buildings uses the relationship between the indoor comfort temperature and the outdoor temperature to delineate acceptable zones for indoor temperature in naturally conditioned buildings (ASHRAE 2004). The standard defines zones within which 80% or 90% of building occupants might expect to find the conditions acceptable (Nicol et al 2012) as shown in figure 1.

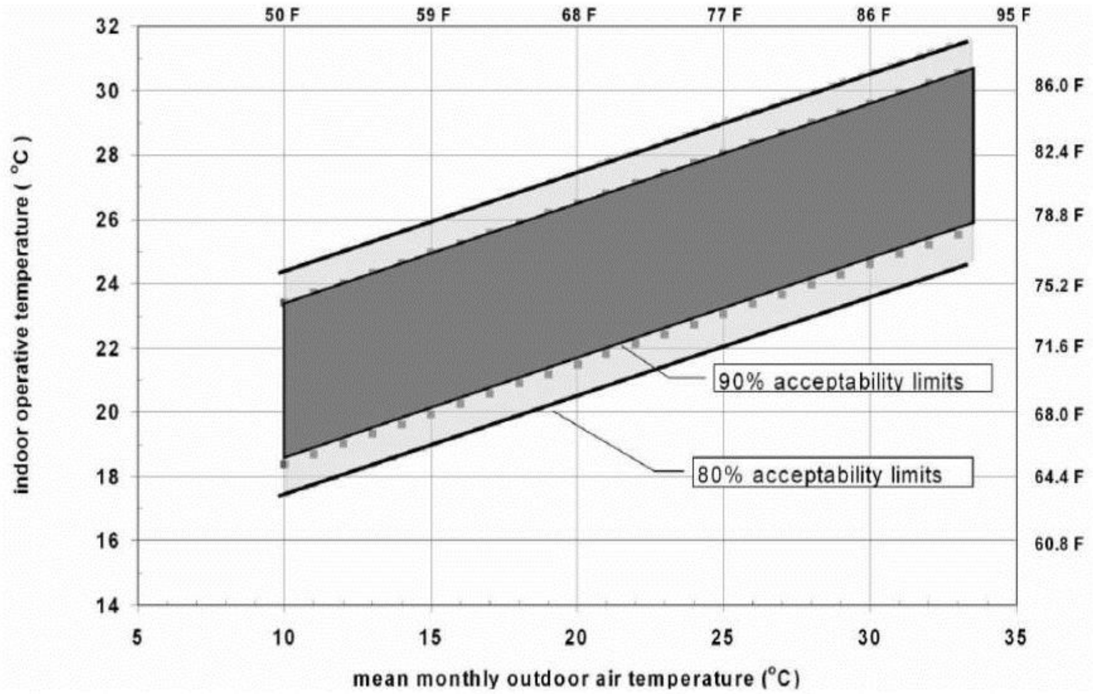


Figure 1 Acceptable operative temperature ranges for naturally conditioned spaces (Source: ASHRAE Standard 55-2004)

In order to assess the acceptable indoor temperatures in classrooms using the adaptive model in this study, the City of Tshwane (CoT) mean monthly outdoor air temperatures are used. The recommended temperature range for CoT in September, with the monthly mean temperature at 19°C, is ±20.1°C - ±27°C and will achieve 80% occupant acceptability; whilst ±21°C - ±26.2°C will achieve 90% occupant acceptability. For October the monthly mean temperature is 21°C and temperatures ranging from ±21°C - ±27.8°C will achieve 80% occupant acceptability and temperatures ranging from ±22°C - ±27°C achieve 90% occupant acceptability (See figures 45 & 46).

The Bill of Rights Section 24(a) of the South African Constitution states that everyone has the right to an environment that promotes health and wellbeing. The South African built environment legislation is responsible for ensuring that buildings promote the health and wellbeing of users through the supportive built environment legislation (Gibberd 2009).

Legislation on health and wellbeing in the built environment is found in the Building Regulations and in the Occupational Health and Safety Act No. 181 of 1993. The Building Regulations set out minimum standards for indoor environment quality, such as lighting and ventilation, in the South Africa National Standards (SANS) 10400– O: 2010 and SANS 10400–XA: 2011 (SABS 2011a & 2011b); however, the Building Regulations do not address thermal comfort standards requirements (SANS 10400 –A: 2010, Gibberd 2009). The Occupational Health and Safety Act addresses health and wellbeing through the Facilities Regulation and Environmental Regulation for Workplaces. The Facilities Regulations set out minimum standards for sanitation, changing rooms, dining rooms, drinking water and seating. The Environmental Regulations for Workplaces sets out requirements for hot and cold working environments, lighting, windows, ventilation, space and noise (Gibberd 2009). The thermal conditions addressed in this regulation are for extreme temperatures below 6.0°C and above 30.0°C, and exclude temperatures as described above as being within the acceptable range for learners in school environments.

The legislation for the built environment fails to provide temperature requirements for different building spaces such as schools, offices, houses and hospitals. It also fails to respond to the thermal requirements of sections of the population that are most sensitive to heat and cold such as the sick, babies, children and the elderly (Gibberd 2009).

Although the built environment legislation fails to legislate and support acceptable temperatures for learners in schools, there are studies that emphasise the importance of thermal considerations in South African school buildings by the Council for Scientific and Industrial Research (CSIR) (1965, 1988), Candiotes (1997) and Gibberd & Motsatsi (2013). The South African Department of Basic Education (2008) has also identified that South African school buildings fail to provide enabling physical learning environments, and suggests that the South African school buildings require evidence based research on building performance and indoor environmental quality (SA. Department of Basic Education 2008).

The South African Department of Basic Education has published the *National Policy for equitable provision of enabling physical and learning environment on schools (2010)* and *Guidelines relating to the planning for public school infrastructure (2012)* for benchmarking school facilities, recognising the importance of thermal environments and other indoor environmental factors in achieving a conducive learning environment. However, these documents refer to the Building Regulations and the Occupational Health and Safety Act that have failed to specify measurable limits for temperature in schools, as explained above.

There is insufficient research (Candiotes 1997, SA. Department of Basic Education 2008, Gibberd 2009, Gibberd & Motsatsi 2013) on thermal comfort legislation and considerations in South African schools. However, compliance with the recommended ambient air temperature ranges by the CIBSE guide A-2006 and ASHRAE standard 55-2004 could be one way of ensuring that learners' human rights are fulfilled as indicated in the Bill of Rights Section 24(a) of the South African Constitution.

Therefore, the subject of this study is to develop a learner thermal comfort protocol specifically for school classroom thermal evaluation. The protocol will be tested in the evaluation of the thermal comfort conditions of two South Africa primary schools in Mamelodi Township. The objective is to contribute to knowledge on thermal comfort evaluation in schools which can be used in the development of thermal comfort regulations.

1.2 **Problem statement**

The South African built environment legislation fails to set thermal comfort standards in school buildings and does not provide for the fulfilment of learners' right to environments that promote health and wellbeing as required by law.

1.3 **Research questions**

1.3.1 **Question 1**

What is thermal comfort and how is it assessed in naturally ventilated classrooms?

1.3.1.1 Sub-questions:

i. Why is thermal comfort important?

ii. How is thermal comfort defined in various standards?

iii. What methodology and protocol do these standards follow to assess/measure thermal comfort?

iv. Why is the ASHRAE 55-2004 standard most applicable to South African thermal environment?

1.3.2 **Question 2**

What concepts can be drawn from ASHRAE 55-2004 and ISO 7730-2005 standards to develop learner thermal comfort protocols applicable to school classrooms?

1.3.2.1 Sub-questions:

i. How can the concepts be interpreted in the development of learner thermal comfort protocols that are applicable to school classrooms?

ii. How can learner thermal comfort protocols be developed to capture thermal comfort in the classroom?

1.3.3 **Question 3**

What does the data collected using the learner thermal comfort protocols indicate about the thermal comfort conditions and design of protocol?

1.3.3.1 Sub-questions:

i. What is the actual air temperature in classrooms?

ii. Do field measurements indicate compliance with ISO 7730-2005 and ASHRAE 55-2004 standards?

iii. Are learners satisfied with the thermal environment in their classrooms?

iv. What are the learners' thermal comfort preferences?

1.3.4 **Question 4**

Is there a relationship between thermal comfort ASHRAE 55-2004 and ISO 7730-2005 standards recommendation and learners' perceptions?

1.4 Research aim and objectives

1.4.1 Research aim

The research aims to develop and test learner thermal comfort protocols (LTCP) through conducting a critical review of existing thermal comfort standards and a field study to ascertain the relationship between thermal comfort standards and learners' perceptions.

1.4.2 Research objectives

The research objectives are as follows:

i. To review thermal comfort standards' methods and protocols for naturally ventilated spaces;

ii. To iteratively develop methods and learner thermal comfort protocols (LTCP) for naturally ventilated spaces for South African school classrooms;

iii. To use the developed methods and learner thermal comfort protocols (LTCP) to collect data;

iv. To assess if there a relationship between ASHRAE 55-2004 and ISO 7730-2005 standards' recommendations and learners perceptions.

1.4.3 Methodology

This study will follow the methodology outlined below:

i. Critically review thermal comfort standards methodologies and write a learner thermal comfort protocol;

ii. Use learner thermal comfort protocol quantitative methods to collect data from learners on their individual perception measurements through the use of close-ended questionnaires;

iii. Use learner thermal comfort protocol quantitative methods to collect data of the actual temperature measurements in the occupied and unoccupied classrooms through the use of data loggers;

iv. Analyse the collected data and assess if the results meet the recommended indoor ambient air temperature range;

v. Compare actual data with learners' thermal comfort perception;

vi. Assess learners' satisfaction with the ambient air temperature;

vii. Assess if there a relationship between ASHRAE standards and CIBSE A-2006 temperature recommendation and learners' perceptions.

1.5 Thesis statement

An air temperature that is above 25.0°C in public primary school classrooms may negatively impact on learners' health, wellbeing and productivity.

1.6 Hypothesis

Ordinary primary school classrooms do not meet thermal comfort standards temperature recommendations.

1.7 Delimitations of the study

The delimitations of the study are listed below.

i. This study measures the thermal comfort performance of the indoor environment in township primary school classrooms within the City of Tshwane (CoT), Mamelodi Township. The climate in CoT is categorised as temperate in SANS 10400-XA: 2011 (SABS 2011b).This climate is representative of the majority of the climate types found in

South Africa. Buildings in this climatic region are generally designed to maintain comfortable indoor temperatures by minimizing heat gain during the daytime and maximising heat loss at night in hot seasons, and the reverse in the cold seasons.

ii. This study will focus on primary schools because primary school education is the most important phase of a child's education; it is also the foundation for further career education and ensures the broad-based development of children's cognitive, social, emotional, cultural and physical skills. At this level children are at their most formative stage and the environment should be conducive to their development.

iii. This study will focus on primary school buildings because they are specially designed to meet the requirements of learner and teachers. Hence, special consideration is placed on aspects such as scale, space, form, colour, texture and indoor environment.

iv. This study will focus on classrooms because that is where learners spend most of their school time and are mostly likely to be affected by the conditions of the indoor environment in which they are placed.

v. This study will focus on permanent classroom structures in primary schools, not temporary and prefabricated classrooms.

vi. This study will not cover the impact of the physical learning environment on learning or academic outcome.

vii. This study will focus on classrooms which accommodate grades 3 - 7. The selected grades normally accommodate age groups of 9 - 14/15 years (see chapter 2 on literature research on primary school uses for a further explanation).

viii. This study will focus on classrooms with these typical characteristics:

- Occupied for approximately 6 - 7 hours (8am-2pm) on school days, including breaks;
- The area of the classroom is approximately 48 - 60 m^2 (square meters);
- The classroom must be naturally ventilated;
- There is environmental control, whereby the teacher controls the opening and closing of windows and door;
- A variety of lessons must take place in one room with children mainly sitting.

ix. This study will focus on the use of the learner thermal comfort protocol to evaluate thermal comfort in the existing selected classrooms and therefore follows the general requirements for the application of thermal comfort standards, that is:

- the specifying of **space** to which the standard will be applied;
- the consideration of activity and **clothing** of occupants.

x. This study will use ASHRAE 55-2004 standard recommended data loggers to record air temperature only and age appropriate surveys to record thermal comfort and other perceptions of the indoor environment. The measurement of air temperature will be made with the assumption that radiant temperature is equal to the air temperature, that the air is still at 0.2m/s, the relative humidity is at 50%, the metabolic rate determined by activity when sedentary is 1.0 met and clothing insulation for the summer school uniform is at around 0.5 - 0.8clo.

1.8 Limitations of study

The limitations of this study are listed below.

i. The schedule for the field study (collection of data) is determined by the school program. Therefore the intention of gathering data in the hottest summer days may not occur.

ii. The selection of classrooms to be studied will be made by the school principal so that interruptions to the normal school program are avoided. This may limit the number, type and location of classroom required for evaluation (e.g. North/South facing).

iii. Desk configurations/layout may change based on lesson. Movement of a desk may have an effect on the data that is required to be collected at a specified spot.

iv. The sensitivity of sensors used to record other thermal environment parameters, such as radiant temperature data and air speed limit this study to measure air temperature and relative humidity. Temperature data loggers are robust and able to withstand tempering by the students and can be placed anywhere securely in the classroom, without recordings being disrupted.

v. Temperature data loggers may malfunction resulting in the failure of data being recorded.

vi. Learner behaviour is very important in adaptive thermal comfort; however, it was not included in the study because this would require the researcher to focus on an individual class for a lengthy period. This would result in the scope of the study being reduced.

1.9 Definition of terms and concepts

1.9.1 Ambient air temperature

The temperature of the surrounding air.

1.9.2 Environmental controls

Means by which the physical environment can be controlled: these may be active, e.g. heating or cooling systems, fans etc., which use energy; or passive, such as openable windows, blinds, etc. (Comfortable Low Energy Architecture 2004). The environmental controls are part of a greater feedback mechanism in the thermal regulatory system.

1.9.3 Learner

Any person receiving education or obliged to receive education in terms of the South African Schools Act 84 of 1996 (South Africa 1996).

1.9.4 Naturally conditioned buildings

Buildings in which windows are used as the main means of controlling the indoor temperature (ASHRAE 55-2004).

1.9.5 Ordinary school

A school that does not cater for learners with special needs (South Africa 1996).

1.9.6 Operative temperature

The combined effects of the mean radiant temperature and air temperature (ASHRAE 55-2004).

1.9.7 Physical school environment

The physical school environment encompasses the school building and all its contents (SA. Department of Basic Education 2008).

1.9.8 Primary schools

Primary schools offer grades R to 7 and are classified in size from small, medium, large to mega.

i. Small primary schools, with a minimum capacity of 135 learners and up to one class per grade;
ii. Medium primary schools, with a minimum capacity of 311 learners and up to two classes per grade;
iii. Large primary schools, with a minimum capacity of 621 learners and up to three classes per grade;
iv. Mega primary schools with a minimum of 931 learners (SA. Department of Basic Education 2008).

1.9.9 Primary school learners

Children of school going age, that is children aged around 7 - 14 years old as described by the South African Schools Act No. 84 of 1996. Primary school learners are children receiving basic education and are also regarded as minors under the Constitution of the Republic of South Africa (South Africa 1996).

1.10 **Assumptions of the study**

The assumptions made by the study are listed below.

i. This study assumes that public primary schools will fail in providing learners with a thermally comfortable environment because the majority of South African public schools have been built without evident building performance research underpinnings.

ii. This study assumes that the learners' thermal comfort perception is affected only by how the learners' 'feel', not by other factors that may contribute to their perception, such as their health and socio-economic conditions.

iii. This study assumes that the learners' 'satisfaction' is synonymous with 'acceptance' and that 'acceptance' is associated with 'thermal sensations' of 'slightly warm', 'neutral' and 'slightly cool'. On the ASHRAE 55 thermal sensation scale this is numerically represented by -1, 0 and 1 with 0 being neutral.

iv. This study assumes that overcrowding in a classroom may contribute to elevated air temperature in that classroom.

v. This study assumes that the inability of learners, or restrictions placed on learners, to control the systems (windows and doors) that may improve thermal conditions to their satisfaction, such as windows and doors (environmental control), may impact on their thermal perception of their environment.

vi. This study assumes that the clothing insulation value of the uniforms that the learners have on may impact on their thermal comfort perception.

vii. This study assumes that the classroom size, the number of occupants, the design and the building construction may impact on thermal perceptions as well as on actual temperatures in classrooms.

1.11 **Research significance and value**

There is a knowledge gap in analysing and assessing thermal comfort in terms of health and safety of the indoor environment in South African township primary school classrooms.

This study will contribute to thermal comfort research by producing a protocol to measure thermal comfort in school classrooms and a unique thermal comfort perception tool specially designed for children.

The study will also contribute to the Department of Basic Education (DBE) evidence based research on the impact of classroom design on thermal environments which plays an important role with regard to learner's health and learning; and contribute to a school classroom user's manual to enable learners to manage their indoor thermal conditions and school inspectors to inspect the classrooms' health and safety compliance.

1.12 Chapter overview

Chapters	**Overview**
Chapter 2: Review of related literature	Chapter 2 addresses the first research question through explaining and discussing thermal comfort as defined by different thermal comfort standards and methodologies followed to assess it. Chapter 2 also discusses the impact of thermal comfort on learners and precedent research on thermal comfort in school classrooms.
Chapter 3: Identification of pertinent issues	Chapter 3 addresses the second research question on concepts that can be drawn from thermal comfort standards to develop the learner thermal comfort protocol that is applicable for learners in school classrooms. This is followed by the interpretation of concepts for adaptation and adoption by the learner thermal comfort protocol.
Chapter 4: Research methodology / Chapter 5: Analysis and interpretation of data	Chapters 4 and 5 address the third research question on the applicability / usability and testing of the learner thermal comfort protocol in collecting data. The actual air temperature is measured along with learners' perception. These chapters also ascertain and discuss the relationship between the thermal comfort ASHRAE 55 - 2004 and ISO 7730-2005 standards recommendation with learners' perceptions.
Chapter 6: Finding / Chapter 7: Discussion / Chapter 8 : Conclusion and recommendations	Chapters 6, 7 and 8 discuss the study findings, draw conclusions and make recommendations for further research.

2 Review of related literature

2.1 Introduction

The study of literature on thermal comfort in schools shows that thermal comfort is of great concern in schools because it not only interferes with learning but is a health and safety issue. The literature has also highlighted the absence of thermal comfort standards for spaces occupied by children, especially in naturally ventilated classrooms.

Thermal comfort standards and factors that contribute to comfort and discomfort are discussed. The selected thermal comfort literature focuses on research conducted at schools located in temperate, warm and hot climate regions.

Furthermore, the impact of extreme temperatures on children and on learners' cognitive development is discussed. This is followed by a discussion on the physical learning environment in which South African primary school learners are taught.

The review of literature related to thermal comfort is significant in understanding the importance of thermal comfort in naturally ventilated classrooms occupied by children and for the development of the Learner Thermal Comfort Protocol (LTCP).

2.2 Thermal comfort

Thermal comfort is one of the four Indoor Environmental Quality (IEQ) factors (the others being indoor air quality, lighting and acoustics) in the indoor environment that is important in maintaining healthy and comfortable spaces. It is important to understand how occupants feel in the environments / spaces that they occupy to ensure that the occupants' health and productivity is not negatively affected (Parsons 1993).

Thermal comfort is defined as 'the *condition of mind that expresses satisfaction with the thermal environment'* by the three widely used international thermal comfort standards: ISO Standards 7730 (2005), ASHRAE Standard 55 and CEN Standard EN 15251 (Nicol, Humphreys & Roaf 2012).

Thermal comfort is also described as one of the ways one feels about the thermal environment. People describe their feelings about the thermal environment as comfortable or uncomfortable. The experience of the thermal environment is expressed in three ways – that is, thermal comfort, thermal discomfort and thermal stress (CIBSE 2006).

Thermal comfort is when one feels satisfaction with the thermal environment, i.e. neither hot / cold. Thermal discomfort is when one feels uncomfortable, i.e. one feels too hot / too cold but is not made unwell by the conditions – other problems can however occur, such as lower work productivity and increased risk of error in task activities which could potentially cause an accident. Thermal discomfort is therefore undesirable from a health and safety point of view (CIBSE 2006).

Thermal stress is where one feels extreme discomfort from the thermal environment, resulting in potentially harmful medical conditions such as dehydration or heat exhaustion in hot environments or frost bite in cold environments. Respiratory problems can occur and the risk of hypothermia and hyperthermia can occur when the body temperature drops or rises above 37.0°C. This could be harmful and potentially fatal (CIBSE 2006).

The thermal environment, which is defined by four basic environmental factors (air temperature, radiant temperature, humidity and air velocity) and two personal parameters (metabolic heat generated by activity and clothing worn), greatly influences both human physiological and psychological responses which are voluntary and involuntary / physiological autonomic responses that serve to maintain the human body core temperature at 37.0°C (Parsons 1993, Stolwijk 1977).

Physiological human thermoregulation responses include vasodilation, whereby the body loses heat when it is hot through sweating if required. If the body becomes cold then the heat is preserved by vasoconstriction and if required heat is generated by shivering (Parson 1993, Stolwijk 1977).

Psychological human responses include thermal sensations and behavioural responses. Thermal sensation is related to how people 'feel' (hot / cold) and is a sensory experience. Many studies have correlated physical conditions to thermal sensations which resulted in models, such as the static and adaptive models, for predicting the thermal sensations of groups of individuals. These models have been widely used by designers and engineers in attempting to provide comfortable environments (Parsons 1993).

Behavioural responses are also a major component of thermoregulation and rely on thermal sensation and thermal discomfort. This response is related to the putting on or taking of clothes, changing posture or activity. Behavioural responses could also be termed 'technical regulation' which includes the building of shelters and designing environments for human occupancy. Buildings and climatic architecture, together with clothing, can be considered as creating micro-climates that has enabled humans to live anywhere (Hensel 1981, Parsons 1993).

The use of the building's environmental systems (e.g. HVAC) to achieve thermal comfort, results in thermal comfort playing a major role in building sustainability because of the associated high energy consumption (Djongyang, Tchinda & Njomo 2010; Zhang et al 2007).

2.3 **Factors influencing thermal comfort**

To achieve thermal comfort, the body must balance heat loss from the body with the rate at which the body generates heat. Loss of heat from the body happen in four ways: by evaporation (via respiration, perspiration and in emergencies through sweating); radiation and convection (both via the skin surface) and conduction. Most of the energy generated by the body is in the form of heat and is produced through the use of oxygen to metabolise food. Some of the energy is used for maintaining bodily functions and activity. The rate of energy production is known as the metabolic rate and is expressed in met units, where 1 met = 58.2 W/m², which is equal to the energy produced per unit surface area of an average person seated at rest. The surface area of an average person is 1.8 m² (ASHRAE 55-2004, CIBSE 2006, Parsons 1993).

Heat is being produced by the body all the time and the amount of heat being generated depends on activity. The level of activity determines the heat produced by the body; therefore, the higher the activity level, the higher the body's heat production and vice versa (Parsons 1993).

The base heat production is around 60Watt (W) for an average person sleeping, around 140W is generated by the body when doing office work and heat generation increases to around 250W when doing physical activities such as dancing / gym work (CIBSE 2006, Parsons 1993).

Heat loss and gain is controlled by one's activity and clothing level. Clothing provides a thermal resistance between the body and its environment and also maintains the body in an acceptable thermal state (Parsons 1993). The amount of thermal insulation worn has a substantial impact on thermal comfort. Clothing insulation is expressed as a clo-value (I_{cl}). The ASHRAE 55-2004 Standard lists estimates of clothing insulation (ASHRAE 55-2004); for example, a typical school summer uniform ensemble for girls in South African schools would include a knee-high skirt, short sleeve shirt and sandals equating to about $0.54I_{cl}$.

Environmental factors that play a major role in heat loss are air temperature and radiant temperature. Each mode of heat transfer depends on different environmental factors, e.g. evaporation and convection are affected by air temperature and air velocity. Heat loss and gain is also affected by the outside surrounding environment and in buildings the internal environmental factors, i.e. temperature, humidity, air movement and air quality depend on the design of the building, the operation of building services, the use of space and the external weather conditions (CIBSE 2006).

2.4 Thermal discomfort

Thermal discomfort can be caused by the unwanted cooling or heating of the whole body or of one particular part of the body. The unwanted cooling or heating of one particular part of the body is known as *local discomfort*. The most common local discomfort factors are radiant temperature asymmetry (cool or warm surfaces), draught (defined as local cooling of the body caused by air movement), vertical air temperature difference, and cold and warm floors (ISO 7730-2005, ASHRAE 55-2004).

People are more sensitive to the radiant temperature asymmetry caused by warm ceilings or cool walls. Radiant temperature asymmetry for ceilings should not be 5°C greater than the surrounding air and the walls should not be 23°C greater than the surrounding air (ISO 7730-2005; ASHRAE 55-2004).

The draught sensation depends on the air speed, the air temperature, the turbulence intensity, the activity level and the clothing worn. Sensitivity to draught is greatest where the skin is not covered by clothing especially the head and leg region (ASHRAE 55-2004).

Vertical air temperature difference may cause discomfort when the air temperature at the head level is warmer than at the ankle level. The allowable air temperature difference between head and ankles should not be greater than 3°C (ASHRAE 55-2004).

Cold and warm floor temperature surface can cause discomfort due to contact with the floor surface. The allowable range for floor temperatures when occupants are wearing light weight indoor shoes is between 19°C and 29°C (ASHRAE 55-2004)

2.5 Research on thermal comfort

Research on thermal comfort in buildings has taken one of two main approaches:

i. *Laboratory based studies*: based on experimental work carried out in a special laboratory or climate chamber;

ii. *Field studies*: based on surveys in the field asking people about their feelings of comfort.

In *laboratory-based studies* the conditions are controlled, for example by using a climate chamber or a laboratory room where the environmental conditions such as temperature, humidity and air velocity can be accurately controlled and set to specific combinations. People in the chamber or laboratory room are monitored to measure factors such as skin temperature, metabolic rate and sweat rate at different combinations of environmental conditions, and with different specific clothing levels with the insulation value of the clothing known. The aim of laboratory-based studies is to find a specific relationship for thermal comfort that relates metabolic rate, clothing level and environmental conditions (CIBSE 2006).

In *field studies* the conditions are not controlled and people carry out their normal activities, dressed as they choose. People are asked to rate their subjective feelings of thermal comfort on a seven-point descriptive scale such as the ASHRAE or the Bedford scales (see table 1).

The researcher then measures the environmental conditions at the time of the survey, such as temperature, humidity, etc. and relates these to the subjects' feeling of warmth to find any relationship. The aim of field studies is to find a link between certain combinations of the environmental variables and the responses gathered (CIBSE 2006).

Table 1 Scale of warmth from Bedford (1936) and ASHRAE (1966) (Parsons 1993)

Bedford – Thermal comfort scale		ASHRAE – Thermal sensation scale	
Much too warm	7	Hot	+3
Too warm	6	Warm	+2
Comfortably warm	5	Slightly warm	+1
Comfortable	4	Neutral	0
Comfortably cool	3	Slightly cool	-1
Too cool	2	Cool	-2
Much too cool	1	Cold	-3

These two research approaches have led to the development of two methods for specifying comfort conditions; that is, the deterministic methods derived from the laboratory approach and the adaptive methods derived from the field studies approach.

The level of thermal comfort or discomfort in both types of model is often expressed in terms of the percentage of people who are happy or not happy with the conditions (CIBSE 2006).

2.5.1 Deterministic methods (also known as static model)

The deterministic method was used by Fanger (1970) to develop comfort temperature thresholds and these form the basis of the International Standard for comfort in office spaces. Fanger uses PMV (predicted mean vote) and PPD (predicted percentage dissatisfied) to predict acceptable comfort conditions. The PMV is the mean value of the votes on a comfort scale of a large group of people who are all exposed to the same environment and have the same clothing level and activity. The term PPD is intended to represent the way a large number of people would judge their feeling of comfort within the space so it could be thought of as the predicted percentage of persons who would be dissatisfied with a particular condition. PMV and PPD can be related such that a PMV of ±0.5 (where +1 is slightly warm and –1 is slightly cool) relates to a PPD of 10%, i.e. around 10% will be dissatisfied (CIBSE 2006) (see table 2).

Table 2 The 7 point ASHRAE and Bedford descriptive scales in relation to the thermal sensation votes (PMV AND PPD %) (ISO 7730-2005)

Bedford – Thermal comfort scale		**ASHRAE – Thermal sensation scale**		**PMV**	**PPD %**
Much too warm	7	Hot	+3	+2	75
Too warm	6	Warm	+2	+1	25
Comfortably warm	5	Slightly warm	+1	+0.5	10
Comfortable	4	Neutral	0	0	5
Comfortably cool	3	Slightly cool	-1	-0.5	10
Too cool	2	Cool	-2	-1	25
Much too cool	1	Cold	-3	-2	75

The PMV / PPD index is a mathematical model of human thermal physiology, calibrated against the warmth sensations reported by people during experiments in climate-controlled spaces. This method treats all occupants in the same manner and disregards location and adaptation to the thermal environment. It suggests that the indoor temperature should not change as the seasons do. Rather, there should be one set temperature year-round. This is taking a more passive stand in that humans do not have to adapt to different temperatures since it will always be constant (CIBSE 2006).

The ASHRAE Standard 55-2010 uses the PMV model to set the requirements for indoor thermal conditions. It requires that at least 80% of the occupants be satisfied (Parsons 1993)

2.5.2 Adaptive methods

The adaptive approach to comfort has been developed from field studies of people in their daily life and aims to provide guidance that is relevant to ordinary living conditions.

The adaptive approach does not require knowledge of the clothing level and the metabolic rate of occupants in order to establish the temperature required for thermal comfort, but takes a more behavioural approach. It is based on the observation that people, given both the time and the opportunity, do take various actions in order to adapt to their environment and achieve thermal comfort (CIBSE 2006).

People adapt to changed conditions in various ways, from involuntary mechanisms such as shivering or sweating to voluntary ones such as changing their activity or their clothing or closing a window blind. The adaptive model is based on the idea that outdoor climate influences indoor comfort because humans can adapt to different temperatures during different times of the year. The adaptive hypothesis predicts that contextual factors, such as having access to environmental controls and past thermal history, influence building occupants' thermal expectations and preferences (de Dear & Brager 1998).

The adaptive chart relates indoor comfort temperature to prevailing outdoor temperature and defines zones of 80% and 90% satisfaction (see figure 1). In order to apply the adaptive model, there should be no mechanical cooling system for the space; occupants should be engaged in sedentary activities with metabolic rates of 1-1.3 met, and a prevailing mean temperature greater than 10°C and less than 33.5°C. This model applies to occupant-controlled, natural conditioned spaces, where the outdoor climate can actually affect the indoor conditions and so the comfort zone. Adaptive models of thermal comfort are implemented in other standards such as European EN 15251 and ISO 7730 (ASHRAE 55 2004).

2.5.3 **Thermal comfort standards**

The most frequently used standards to prescribe thermal comfort in the indoor environment are the American ASHRAE Standard 55-2004: Thermal environmental conditions for human occupancy; the ISO 7730: Moderate thermal environments–determination of the PMV/ PPD indices and specification of the conditions for thermal comfort (2004) from the International Standard Organization and the Comite European de Normalisation (CEN) Standard EN15251 (2007) from Europe (Parsons 1993). ASHRAE Standard 55-2004 which is in close agreement with the ISO 7730 and ISO 7726 (Ergonomics of the thermal environment) standards is the first international standard to include an adaptive component. The adaptive standard was developed using the collected data in the ASHRAE RP884 database. The standard uses the relationship between the indoor comfort temperature and the outdoor temperature to delineate acceptable zones for indoor temperature in naturally conditioned buildings (Parsons 1993, Nicol et al 2012).

The ISO 7730 standard from the International Standard Organization (ISO) sets out the calculation and uses the PMV / PPD index. It includes some criteria for local comfort, a table of measured values of the thermal insulation for various clothing and ensembles and a table of typical values for the metabolic rates of a variety of activities. The standard also specifies categories of buildings according to the range of PMV that occurs within them. For example, ‘category A’ buildings maintain their indoor environment within ±0.2 PMV (PPD ≤ 6%), ‘category B’ maintain their indoor environment within ±0.5 PMV (PPD ≤ 10%), and ‘category C’ maintain their indoor environment within ±0.7 PMV (PPD ≤ 15%) (Parsons 1993, Nicol et al 2012, ISO 7730-2005) (See tables 3 & 4).

Table 3 The 3 categories of thermal environment (ISO 7730-2005)

Category	**Thermal state of a body as whole**		**Operative temperature (°C)**		**Max. mean air velocity (m/s)**	
	PMV	*PPD %*	*Summer (0.5 clo) Cooling*	*Winter (1 clo) Heating*	*Summer (0.5 clo) Cooling*	*Winter (1 clo) Heating*
A	-0.2<PMV<+0.2	<6	23.5 - 25.5	21.0 - 23.0	0.18	0.15
B	-0.5<PMV<+0.5	<10	23.0 - 26.0	20.0 - 24.0	0.22	0.18
C	-0.7<PMV<+0.7	<15	22.0 - 27.0	19.0 - 25.0	0.25	0.21

Table 4 Design criteria for classrooms (ISO 7730-2005)

Type of building	Activity (W/m^2)	Category	Operative temperature (°C)		Max. mean air velocity (m/s)	
			Summer	*Winter*	*Summer*	*Winter*
Classroom	70	A	23.5 - 25.5	21.0 - 23.0	0.12	0.10
		B	23.0 - 26.0	20.0 - 24.0	0.19	0.16
		C	22.0 - 27.0	19.0 - 25.0	0.24	0.21

The CEN Standard EN15251 of 2007 contains a similar categorisation as the ISO 7730 Standard but its categories are defined by the nature of the building not the quality of the indoor environment. The adaptive standards in the EN15251 Standard are similar to the ASHRAE 55, but it uses data from European SCAT's project that was collected from five European countries instead of the ASHRAE RP884 database (Nicol et al 2012).

2.6 Summary

The ASHRAE 55-2004 and ISO 7730-2005 standards are used in the evaluation of the thermal comfort in buildings. The ASHRAE 55-2004 and ISO 7730-2005 standards both contain static and adaptive models' principles and methodologies for the evaluation of spaces. The static model was developed using Fanger's PMV/PPV mathematical model and the adaptive model in the ASHRAE 55-2004 was developed using the RP884 database which included about 22 000 data sets from 160 buildings (naturally ventilated and mechanically ventilated (HVAC)) in different climatic zones worldwide (i.e. hot-humid, Mediterranean, cold, tropical and subtropical zones) (de Dear, Gail & Cooper 1997). Hence, the ASHRAE 55-2004 and ISO 7730-2005 standards will be critically reviewed in the development of the Learner Thermal Comfort Protocol (LTCP) used in the evaluation of thermal comfort conditions in the case studies.

2.7 A critical review of the ASHRAE 55-2004 and the ISO 7730-2005 standards

This study critically reviews the thermal ASHRAE 55-2004 and the ISO 7730-2005 standards based on four (4) criteria; that is **validity**, **reliability**, **usability** and **scope** for applicability as done by Parsons (n.d.). The same criteria will be used to assess the applicability of the Learner Thermal Comfort Protocol (LTCP).

i. **Validity** is concerned with whether the assessment method or index accurately predicts thermal comfort as perceived by people (Parsons n.d.).

ii. **Reliability** is concerned with whether a standard used to assess thermal comfort would give the same prediction if repeatedly used to assess exactly the same conditions. If a procedure is ambiguous or non-specific (in relation to where to measure, what to measure, when to measure, etc.), it will reduce reliability (Parsons n.d.).

iii. **Usability** is concerned with whether the users of a standard can use it correctly (Parsons n.d.)

iv. **Scope** is concerned with what it does and does not apply to (Parsons n.d.).

2.7.1 ISO 7730-2005 standard

i. **Validity**

The validity of ISO 7730 is supported by laboratory studies rather than field studies. However, ISO 7730 has been criticised because of its lack of theoretical validity and the fact that it is outdated (the PMV/PPD indices were established in 1970). Since then there have been improvements to the human heat balance equation (Parsons n.d.).

The validity of ISO 7730 is dependent on the validity of ISO 8996 – metabolic rate – and ISO 9920 – clothing. The validity of the ISO 7730 as a universal international standard is questionable because it does not include all cultures and population (Parsons n.d.).

ii. Reliability

Defining the PMV/PPD in an international standard provides the major advantage of ensuring that when it is calculated anywhere in the world the same result will be obtained (Parsons n.d.).

iii. Usability

It is not clear who the users of ISO 7730 are intended to be but it is assumed that those involved in environmental design and assessment, building services, engineering and ergonomics would use it (Parsons n.d.).

iv. Scope

The ISO 7730 uses the PMV/PPD index which was developed using North American and European people and applies to healthy men and women. Children are not considered. The standard notes that deviations may occur due to ethnic and national-geographic deviations and for people who are sick or disabled. The standard applies to indoor environments where steady state thermal comfort or moderate deviations from comfort occur (Parsons n.d.).

2.7.2 ASHRAE 55-2004 standard

i. Validity

The ASHRAE 55 standard has continuously undergone public and ASHRAE review and it incorporates the relevant research and experience gained since the 1992 revision.

ii. Reliability

Research confirming the reliability of the ASHRAE standard in giving the same prediction if repeatedly used to assess exactly the same conditions has not been found by this study.

iii. Usability

The standard is intended for use in design, commissioning, and testing of buildings and other occupied spaces and their HVAC systems and for the evaluation of thermal environments**.** The standard is intended primarily for sedentary or near sedentary physical activity levels typical of office work (ASHRAE 55-2004).

iv. Scope

The ASHRAE 55 standards address the following environmental factors temperature, thermal radiation, humidity, and air speed; the personal factors are those of activity and clothing. It is intended that all the criteria of the standard be applied together.

The standard specifies thermal environmental conditions acceptable for healthy adults at atmospheric pressures equivalent to altitudes up to 3 000 metres in indoor spaces designed for human occupancy for periods of not less than 15 minutes.

2.8 Summary

The international comfort standards such as those of ASHRAE and the International Standards Organizations (ISO) are almost exclusively based on theoretical analyses of human heat exchange performed in mid-latitude climatic regions in North America and northern Europe.

They exclude the assessment of buildings occupied by children and hence they have to be applied carefully when assessing such environments. This implies that the LTCP should extract and study methods and protocols followed by research studies that have applied these standards in classroom environments.

2.9 The classroom and learners

Learners and educators spend the majority of their time indoors, in school buildings or classrooms (Haddad, King & Osmond 2012). Therefore, having a satisfactory indoor environment quality is important to facilitate the education process. The indoor environment must satisfy the requirements for both teacher and learners (Le Roux 1968).Children are also more vulnerable to the environments that they find themselves in, and have little or no control on the environmental conditions imposed on them (Wigle 2003).

2.9.1 The impact of the indoor classroom environment on learner development

There are numerous studies relating indoor environments to health and learners' academic performance. Studies such as those conducted by Mendell and Heath (2005), review literature on how indoor environmental quality and thermal conditions in schools may relate to learners' performance.

The internal environment conditions such as light, noise, volatile organic compounds (VOCs), and air and thermal quality are important for the overall wellbeing and learning processes of children because, unlike adults, children require high volumes of clean air, environments with good acoustics to improve student hearing and concentration and comfortable internal temperatures to decrease irritability and increase their attention span and mental efficiency (Schneider 2002).

Poor learning environments have been found to contribute to learners' irregular attendance and dropping out of school, as well as educators' absenteeism and the ability to engage in the teaching and learning process. The physical appearance of school buildings are shown to influence students' achievements and educators' attitude towards the school (South Africa Department of Education 2008).

In the article on '*Child development and the physical environment'* Evans (2006) discusses the characteristics of the physical environment that influence child development such as toxins found in the environment (i.e. lead and mercury), crowding and noise. Evans, Lepore, Shejwal, & Palsane (1998) and Evans, Lercher, Meis, Ising & Kofler (2001), found that conditions such as crowding in the classroom negatively influence students' motivation in task performance and increase the level of helplessness in girls.

Furthermore, Cash (1993) investigated the relationship between school building conditions, student behaviour and student achievement and found significant differences between the achievement scores of students in substandard buildings than those in above-standard buildings. Bowers and Burkett (1988) investigated differences in health, attendance, behaviour and achievement and found that that there was a relationship between the physical environment and health, attendance, behaviour, and student achievement.

Evans and Stecker (2004) found that the quality of the physical environment influences child development especially in cases of children from low-income families who are exposed to 'multiple suboptimal physical and social environmental conditions.

2.10 **Summary**

The overall condition of the school physical environment plays an important role in the productivity, health and safety of learners.

2.11 **Research on thermal comfort in classrooms**

Studies conducted by Wyon (1993) and Wyon, Fanger, Olesen & Pederson (1975) confirm that extreme thermal conditions have specifically been found to increase irritability and reduce students' attention span and mental efficiency.

Recent studies on thermal comfort in classrooms investigate the applicability of the thermal comfort standards in different climatic and cultural contexts. Appah-Dankyi & Koranteng (2012), Wong & Khoo

(2002) and Liang, Lin & Hwang (2012) investigate the applicability of the ASHRAE 55 on classrooms occupied by learners in the tropics. They found that the indoor temperature fell out of the ASHRAE 55 recommended temperature range, but was accepted by learners. However, cooler temperature sensations were preferred by learners.

Corgnati, Ansaldi & Filippi (2009), ter Mors (2010) and Teli, James & Jentsch (2013) investigate the applicability of the PMV and adaptive model in predicting learners' thermal comfort in the classroom. Hwang, Lin & Kou (2006) explored learners' adaptive behaviours, their thermal neutrality and thermal acceptance in a hot-humid climate using the adaptive model. They found that the majority of the learners accepted the thermal conditions even though the actual temperature fell outside of the ASHRAE 55 comfort range.

Teli et al (2013) and Liang et al (2012) found that learners were more sensitive to higher temperatures than adults. Learners aged 7 - 11 years old found temperatures at 4°C lower than PMV and 2°C lower than the EN 15251 adaptive thermal comfort prediction range comfortable (Teli et al 2013).

Liang et al (2012) found a strong relationship between the indoor and outdoor temperatures. The adaptive model developed for learners was steeper than the ASHRAE predicted adaptive model. The learners' neutral temperature was at 29.9°C and 2.3°C higher than suggested by ASHRAE 55. Table 5 below summarises the objectives / aim, methodologies and findings of recent research on thermal comfort in classrooms.

Table 5 Thermal comfort research in classrooms

Year	Researcher	Location	Season	Climate	Type of ventilation	Research objectives/aims	Methodology	Research findings
2002	Wong, NH & Khoo, SS	Singapore	Summer	Tropical	NV+CF	- Find thermal conditions in classroom & compare with that prescribed by ASHRAE standard 55-92; - Investigate occupants thermal comfort perception & acceptability using ASHRAE & Bedford scales, votes of preference and acceptability; - Determine neutral temperature, preferred and acceptable temperature ranges.	- 15 classrooms surveyed; - Quantitative and qualitative methods – collected daily ; - Spot measurement of indoor variables; - Thermal comfort questionnaire; - Physical measurement at 5 points of classroom; - Measured :air temperature, relative humidity and air velocity, and mean radiant temperature; - Estimated measurement: metabolic rate (1.2 met) and clothing insulation(0.45 clo) – according to ASHRAE 55; - Measurements taken 1m above floor; - Measured: Thermal sensation votes (TSV) and thermal preferences.	- Thermal conditions do not fall within ASHRAE standard 55-92 comfort zone temperature range, but temperature beyond accepted – 27.1°C to 29.3°C; - Bedford scales preferred method of assessing thermal acceptability; - Neutral temperature at 28.8°C; - Cool thermal sensations preferred.

2003	Kwok, AG & Chun ,C.	Japan	Summer	Sub-tropical	NV+CF	- Examine the relationship of comfort in NV and AC classrooms; - Examine the application of thermal comfort standard (ASHRAE 55-92) in context of the Japanese climate and culture.	- 2 classrooms, 74 learners surveyed; NV=43, AC=31; - Use of climatic measurement system, fitted into a laboratory cart to measure from 1.1mfrom the floor; - Measured: air temperature, relative humidity and air velocity, and mean radiant temperature; - Questionnaire answered while actual recordings being taken; - Questionnaire used ASHRAE Thermal Sensation Scale; - Measurement of personal factors: metabolic rate (1.0 met) and clothing insulation – sketch drawings recorded; - Used ASHRAE 55-1992 methods to assess comfort.	- Thermal conditions in NV classrooms did not fall within ASHRAE standard 55 - 92 comfort zone temperature range, but AC classrooms did; - Occupants accepted indoor condition, but preferred cooler conditions; - Adaptive behaviours were observed.
2006	Hwang,Lin, Kuo	Taiwan		Hot-humid	NV+AC	- Find range of thermal acceptability, neutral temperatures and preferred temperature; - Compare findings with those prescribed by ASHRAE Standard 55; - Determine which factors	- 7 Universities,36 classrooms surveyed; NV=10, AC=26; - Quantitative and qualitative methods used; qualitative data collected while quantitative data is collected; - Questionnaire used ASHRAE 7-point Thermal	- Temperatures fell outside ASHRAES 55 summer comfort zone, but more than 80% of students found it acceptable; - Preferred temperature of 24.7°C; - Neutral temperature of 26.3°C; - Wider temperature range accepted.

						affect learners thermal sensation; - Determine relationship between indoor climate and subjects comfort responses.	Sensation Scale and thermal preference scale, and asked preference level; - Questionnaire included questions on indoor environment aspects; and clothing checklist; - Use of climatic measurement system, fitted into a laboratory cart to measure: air temperature, relative humidity and air velocity; mean radiant temperature was estimated from global temperature; - Transducers – ASHRAE 55 & ISO 7726/7730 compliant; - Measurement of personal factors: metabolic rate (1.0 met) and clothing insulation – sketch drawings recorded on checklist.	
2007	Zhang, G, Zheng, C, Yang, W, Zhang, Q & Moschandreas DJ.	China	-	Sub-tropical	NV+CF	- Generate a general profile of thermal environment in NV classrooms; - Investigate occupants perception level of thermal comfort; - Find out characteristics of thermal condition in classroom and students' thermal perception; - Compare result with	- 2 University buildings surveyed, 25 classrooms & 1 273 students responded; - Thermal comfort variables measured at the same time as student survey; - Instrument used to record data – psychorometer (temperature and RH) and thermal-anemometer. Mean radiant temperature estimated from globe temperature; - Instruments positioned at 5 points;	- Thermal environment acceptable to majority of students;

						previous studies and relevant standards; - Compare collected data with thermal sensation models.	- Personal parameters estimated from ASHRAE 55: Metabolic rate 1.2 met, clothing insulation 0.65-1.93clo.	
2009	Corgnati, SP, Ansaldi, R & Filippi, F.	Italy	Mid-season (Spring, Summer)	Mediterranean / Continent-al	NV	- Investigate thermal comfort through field studies of high school & university; - Subjective investigation of perception of thermal environment (preference and acceptability); - Measure all thermal factors; - PMV and adaptive approach used.	- 2 institutions(1school & 1 university) surveyed; - Quantitative and qualitative methods (collected while data is collected); - 3 different surveys used; - Indoor climatic analyser instrument used in class to measure environmental factors – positioned 600mm above floor & moved around; - 6 micro-data loggers located at student desks – central position; - Many thermal zones determined; - Thermal discomfort measured; - Personal parameters estimated from ASHRAE 55: Metabolic rate 1.2 met, clothing insulation 0.65-1.93clo.	- Thermal preference – slightly warm in winter and neutral in temperate season.
2009	Hwang, Lin, Chen, Kuo	Taiwan	Autumn (Sept-Jan)	Hot - humid	NV	- Investigate applicability of the ASHRAE 55 adaptive model in hot-humid climate; - Explore adaptive behaviours, thermal neutrality and thermal comfort zones;	- 48 classrooms surveyed, 14 public schools, 1 614 participants; - Survey continuous; - Thermal parameters measured; - 4 Data acquisition systems positioned 1.1m and 2.0m above floor; - Questionnaire completed twice a day between	- 87% of learners satisfied with the level of thermal comfort; - 35% of actual indoor environment fell out of ASHRAE comfort range; - Cooler temperature preferred; - 90% acceptability for temperature range of 20.1°C - 28.4°C; 80% acceptability for temperature range of 17.6°C - 30.0°C. The 80%

						- Participants: children under 17 years.	08:00am - 9:00 am and 13:00pm - 2:00pm; - Questionnaire included questions on background, activity, clothing insulation, thermal sensation, preference and acceptability; - Clothing insulation estimated.	acceptability is 1.7°C lower than the ASHRAE recommendation.
2010	ter Mors, S.	Nether-lands	Winter, Spring & Summer (2010)	Temper-ate maritime	NV	- Investigate thermal sensation and clothing insulation of learners aged 9-11.	- 3 schools, 3 classrooms; - Thermal and personal parameters measured; - Used ISO7730 for determination of clothing insulation values and activity levels; - Thermal environment parameters recorded at single location.	- Learners adapt clothing from mean values around 0.9clo in winter to 0.3clo in summer; - PMV model underestimates the mean thermal sensation up to 1.5 scale point and predicts higher comfort temperatures than those indicated by children; Currently applied assessment methods for primary schools are not correct.
2012	Teli, D, Jentsch , MF, James, PAB.	England	Summer (April – July 2011)	Temper-ate	NV	- Investigate the applicability of existing thermal comfort models for predicting children's (aged 7-11) thermal sensation and preference in classrooms; - Look at the impact of building characteristics on learners' thermal sensation and preference; - Study the relation of thermal comfort survey results to the classrooms' long-term thermal performance;	- 8 classrooms surveyed, 230 learners surveyed 6 times, resulting in 1 314 responses; - Multi-functional measuring instrument – located at centre of classroom; - Measurements – thermal parameter and CO_2; - Clothing values 0.4 and 0.35clo; - PMV/PPD calculated.	- Children are more sensitive to higher temperatures than adults – comfort temperatures 4°C lower than PMV and 2°C lower than EN 15251 adaptive thermal comfort predictions; - Building characteristics such as orientation have a strong impact on building occupants' thermal perception, even when they do not affect the thermal sensations.

						- Measure indoor environmental variables; - Compare results with heat balance and adaptive model.		
2012	Appah-Dankyi, J & Koranteng, C.	Ghana	Summer	Tropical	NV + CF	- Investigate learners' perception of comfort and examine prevailing thermal conditions in classroom; - Compare results with ASHRAE standard 55 recommendations.	- 2 classes surveyed, 116 responses; - Quantitative and qualitative methods (collected while data is collected); - HOBO Data logger measuring temperature and relative humidity – located at centre of class.	- Learners' thermal condition acceptance exceeds the ASHRAE 55 recommended temperature range of 26°C - 28°C by 1°C to 5°C.
2012	Liang,Lin & Hwang	Taiwan	All	-	NV	- Investigate the effects of the building envelope regulations on thermal comfort level in NV classrooms (primary & secondary schools); - Compare Adaptive comfort model for children and teenagers with ASHRAE 55 Adaptive model.	- Quantitative and qualitative methods.	- Neutral temperature for the hottest month was at 29.2°C, 2.3°C more than that suggested by ASHRAE 55 (26.9°C). But winter neutral temperature 22.4°C is closer to ASHRAE 55 (23.0°C). - Strong relationship was found between indoor and monthly outdoor temperatures. Adaptive comfort model for children and teenagers is steeper than ASHRAE 55 Adaptive model. - Survey shows that children are more sensitive to increase of operative temperature.
2014	de Dear, R, Kim, J, Candido ,C, Deuble ,M.	Australia	Summer	-	NV+AC +EC	- Conduct thermal comfort survey; - Define preferred, neutral and acceptable temperature for Australian school children.	- 10 primary schools, 3 129 questionnaires; - Quantitative and qualitative methods.	- Neutral and acceptable temperature of 22.5°C; - Operative temperature range 18.5°C - 26.5°C.

2.12 **Summary**

The thermal comfort research of learners in primary schools by Humphreys 1977, found that learners had different thermal perceptions to adults as the children that participated in the research did not change their clothing during the day although the room temperature and mean thermal sensations changed during the day. According to Humphreys (1973) and Teli et al (2013 & 2015), the possible explanation to this thermal comfort difference may be that children seem to be less sensitive to temperature change than adults and have a higher metabolic rate per kilogram of body weight.

Thermal comfort research confirmed that learners in warm / hot / humid and temperate climates accepted temperatures higher than those recommended by ASHRAE 55 but preferred cooler thermal sensations.

The PMV model underestimated the mean thermal sensations and predicted higher comfort temperatures than those indicated by learners and clothing adaptability according to season is important for thermal comfort (ter Mors 2010). However, learners have been found to take limited adaptive actions to adjust to the indoor thermal environment during class hours; they add or remove layers of clothing but cannot freely open or close windows or adjust their activity level (Teli et al 2013; Hwang et al. 2009; Corgnati et al 2009). Building characteristics such as orientation also play an important role in the impact of learners' thermal perception (Teli et al 2013 & 2015).

It is important to acknowledge and understand that the school environment's unique characteristics when compared to adults working and learning environments such as offices, universities and climate chambers used in the development and investigation of thermal comfort standards (de Dear et al 2014). School learners are often engaged in a range of activities in more densely occupied rooms; with limited adaptive opportunities (learners' wear compulsory uniforms and any environmental controls are operated by the teacher). These differences can be expected to affect the learners' perception of comfort; the thermal conditions within school and classroom environments must be considered carefully when analysing field study findings (Zhang et al 2007, Teli et al 2013, de Dear et al 2014).

The methodologies implemented in the thermal comfort research contribute some insight to how the LTCP can be adapted and improved.

2.13 The learner: Primary school classroom users

Learners attending ordinary public primary schools in South Africa are generally children from the age of five to fifteen (5 - 15) with different backgrounds and intellectual abilities. The learners go through three phases of the General Education Training (GET), i.e. Foundation phase, Intermediate phase and Senior phase, before entering that of the Further Education and Training (FET). The learner to teacher ratio in ordinary public primary schools is one (1) teacher per thirty (30) learners (South Africa Department of Basic Education 2012). Table 6 illustrates the grade, the phase of GET and typical age of learner in a specific grade.

Table 6 Primary school users (by author)

Learners			**Learner to Educator Ratio(LER)**
Grade	*Phase*	*Typical Age*	30 learners to 1 teacher
Grade R-3	Foundation phase	5 - 9 years	
Grade 4-6	Intermediate phase	10 - 13 years	
Grade 7	Senior phase	14 - 15 years	

2.13.1 **Primary school learners' development**

Throughout primary school learners' school careers, they will develop and grow in size (weight and height). The learner will develop in four areas, i.e. cognitive, social, emotional and physical. All these traits are dependent on each other for development and influence each other in deferent ways (Ganly 2010a & b). Understanding learner development is important for professionals involved with children so that the appropriate education systems, learning tools and physical environment can be prepared for learners (Ganly 2010a & b).

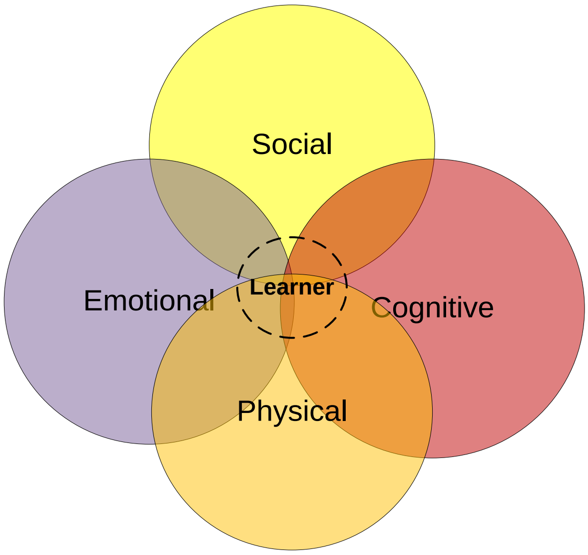


Figure 2 Four areas of learner development (by author)

2.13.2 **Child development theories**

In order to understand schools, why they are structured and organised the way they are; and how they are used, it is important to understand the theories that have impacted on the education system and education pedagogy. School buildings are structured to deliver education pedagogy and develop learners in all four areas of development, but the primary task of the school is to foster the cognitive development of children (Danielsa & Shumowb 2002).

Child development theories, such as Pavlo and Skinner's behaviourist theories, Bandura's social cognitive theory, Piaget's theory of development, Vygosky's socio-cultural theory including theories of learning and pedagogy, have had the greatest impact on instruction and curriculum design in education as well as influence on desk layout (Gail Jones & Brader-Araje 2002).

i. Vygosky's socio-cultural theory

Vygosky believes that social life is primary in the learning process (Blake & Pope 2008); his social theory is applied in schools through the use of cooperative and collaborative teaching strategies such as team-games tournaments, team work and peer to peer tutoring. This emphasises Vygosky's theory on the role of the other in educating, i.e. learners learn from each other while sharing ideas and challenging each other's perspectives (Gail Jones & Brader-Araje 2002).

Vygosky's social theory can be seen in the design and organization of classrooms. Classrooms have designated spaces for small group work, as well as arrangements for whole class discussion (Gail Jones & Brader-Araje 2002). Figure 3 below illustrates the implementation of the social theory in the classroom layout.

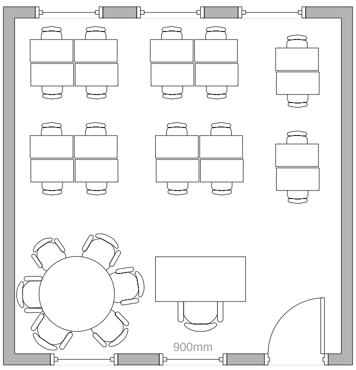


Figure 3 Example of classroom layout to promote group work (by author)

ii. Piaget's theory of development

Piaget believes that the individual is primary in the learning context and that learners are constructive constructors of their own knowledge (Blake & Pope 2008). His cognitive development theories focus more on the development of the individual than on the socio-cultural context (Gail Jones & Brader-Araje 2002). Piaget has had great influence in shaping education and child developmental psychology; however, his theories have also drawn great criticism (Blake & Pope 2008; Cook & Cook 2005).

Piaget's theory of development has been widely used in structuring education curricula, and organising and teaching children according to their age and development. It has also impacted on the learning environment, school design and classroom organisation.

According to Muthivhi (2009), Piaget's theory has had an influence on education practice in South Africa, especially the theory of development and learning performance capabilities associated with the various stages and ages. For example, the age for primary school entry in South Africa is the Reception grade and grade zero (grades R / 0) when the children are at the pre-operational stage and grades one to seven (1 - 7) when the children are at the concrete operational and formal operational stages (South Africa 1996).

Piaget's theory on the stages of development is also evident in how classrooms are structured according to the ages and stages of learners as well as in the classroom layout. Table seven (7) and figure four (4) below illustrate how the South African education system uses the Piaget's stages of development theory.

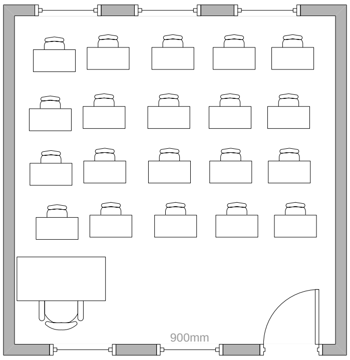


Figure 4 Example of classroom layout to promote individual work (by author)

Table 7 South African primary school education vs Piaget stages of development

South African primary school basic education General Education Training (GET)			Piaget's stages of development
Grade	**Phase R**	**Typical Age**	**Stage of development**
Grade R - 3	Foundation phase	5 - 9 years	Pre-operational stage
Grades 4 - 6	Intermediate phase	10 - 13 years	Concrete operational stage
Grade 7	Senior phase	14 - 15 years	Formal operational stage

Table eight (8) below illustrates Piaget theory on how children process information at different stages of development.

Table 8 Piaget stages of cognitive development (Piaget 1970)

Age	Stage	Performance
Children ages 0 - 2	Sensorimotor stage	Infants know the world through their movements and sensations.

Children ages 2 - 7	Pre-operational stage	Children begin to think symbolically and learn to use words and pictures to represent objects. They also tend to be very egocentric, and see things only from their point of view.
Children ages 7 - 11 years	Concrete operational stage	Children begin to think logically and in a more organised way about concrete events.
Children aged 12 years	Formal operational stage	The adolescent or young adult begins to think abstractly and reason about hypothetical problems. Teens begin to think more about moral, philosophical, ethical, social, and political issues that require theoretical and abstract reasoning.

Learners in grade R (Reception) to grade 2 (ages 5 - 8) are not included in this study although they are starting to think logically about events. Normally children at this age are at the early stages of establishing a sense of competence in school and with peers; of eye and hand coordination (reading and writing) and of developing the capacity for self-control. Learners at this stage normally take time to complete tasks, find it difficult to make decisions and are easily distracted.

This study will focus on learners in grades 3 to 7, within the ages of 9 / 10 and 14 / 15 years. This selection of learners of these ages is based on Piaget's stages of cognitive development theory that has been used in education planning and teaching.

Learners in grades 3 - 7 represent all 3 phases in basic education, see table 9.

Table 9 Grades, phases and typical age in basic education structure (South Africa. Department of Education 2008)

Grade	Phase	Typical Age
Grade 3	Foundation phase	9 - 10 years
Grade 4 - 6	Intermediate phase	11 - 13 years
Grade 7	Senior phase	14 - 15 years

2.13.3 **Heights of learners' aged 9 to 14 (sitting / standing)**

The heights of learners' at sitting and standing position are required for the measurement of ambient temperature. Ambient air temperature is required for the measurement of vertical temperature difference (see figure 18). Table 10 below estimates the learners' eye height sitting and standing, in relation to age.

Table 10 Primary school learners' sitting & standing heights (European school furniture standard BS EN 1729)

Age	Height sitting (eye height)(mm)	Standing (eye height) (mm)	Table height (mm)
9 - 10	920 - 1 045	1 258 – 1 384	640
10 - 11	955 - 1 091	1 302 – 1 457	
11 - 12	992 - 1 113	1 362 - 1 493	710
12 - 13	1 025 - 1 179	1 394 – 1 563	
13 - 14	1 073 - 1 218	1 460 – 1 610	
14 - 15	1 100 - 1 262	1 486 – 1 661	
Average	**1 080**	**1 447**	

2.13.4 **Primary school furniture heights (desks/chairs)**

The primary school furniture height is required for the positioning of data loggers, which measures ambient air temperature. Table 11 below illustrates the height of desks and chairs from the finished floor level.

Table 11 Primary school furniture (SANS 660:2013)

Type	Desk height (mm)	Chair seat height (mm)
Teachers	760	-
Lower primary	575 (+-7)	325 (+-4)
Higher primary	650 (+-7)	400 (+-4)

2.13.5 The learner: Survey instrument

Haddad et al (2012) conducted a study on questionnaire design to determine children's thermal sensation, preference and acceptability in the classroom. Their findings were that earlier thermal comfort surveys mainly focused on adults, and given the concern with the quality and reliability of children's subjective responses, techniques for designing an effective questionnaire for evaluating children's perception of thermal comfort in the classroom were necessary.

Techniques that were adopted from Haddad et al (2012) for the development of this study's learner thermal comfort questionnaire for children are:

i. *Age selection* – the focus on children from the age of seven (7) and above at primary school level, because children at these stages provide more stable answers as they grow older and this has an effect on the reliability of data (Borgers et al 2000, see Piaget stages of development (Piaget 1970)).

ii. *Simplicity and clarity*– it is recommended that the questionnaires are kept as simple as possible, because children need more time to process information compared to adults. Children also have difficulties with interpreting ambiguous questions due to a literal interpretation of words (Holaday & Turner-Henson 1989).

iii. *Using pictures and colour* – using pictures and illustration helps children identify the questions more easily and providing cognitive images familiar with children's feelings and past experiences us helpful, whereas, using words "may fail to describe the exactness of the subjective experience" (Aitken 1969). The other advantage of using cartoon illustrations is that they can be universally understood without any translation.

The only major concern of using such methods in this study is that the level of attractiveness of specific pictures for children may lead to selection of the favoured image, regardless of actual thermal sensation (Haddad et al 2012).

iv. *Using scales for children* – Likert is the type of rating scale which seems to be appropriate for children (Chambers & Johnston 2002, Laerhoven, Zaag-Loonen & Derkx 2004) because it provides discrete choices that can be easily interpreted. Likert scales with cartoon facial expressions to describe children's thermal sensation can be a good option in the place of, and/or in addition to, words in the rating scale (Haddad et al 2012).

2.14 **Summary**

The literature review on children's cognitive development and understanding of the classroom environment (spatial layout and furniture height) is important for the development of appropriate learner thermal comfort surveys for primary school learners and for the determination of sitting and standing heights for measuring the ambient air temperature. Children's ability to respond to survey questions is affected by the development of their cognitive skills (Borgers, Leeuw & Hox 2000; Haddad, King, Osmond & Heidari 2012) and language barriers that may exist in the South African primary school context require surveys to be simple and easy to comprehend.

The finding on children development research influences the decision made in the LTCP in respect to sampling selection, positioning of instrumentation and questionnaire design.

2.15 School infrastructure research

Extensive research has been conducted globally of school infrastructure, such as Tanner & Lackney's (2005) study on educational architecture, Uline & Tschannen-Moran's (2005) study on the quality of schools and student achievement and Barrett & Zhang's (2009) research on optimal learning spaces.

2.15.1 School infrastructure research in South Africa

School infrastructure research in South Africa was well documented by the National Building Research Institute (NBRI) of the Council of Scientific and Industrial Research (CSIR). The NBRI-CSIR school buildings committee conducted comprehensive research on school design standards in the late 1950s and early 1960s.This research was adopted by the government and has influenced the design of South African public schools. However, there is limited research in the evaluation of school buildings performance after occupation.

The lack of current research on South African school infrastructure is made apparent in the following official documents*: National Policy for an Equitable Provision of an Enabling School Physical Teaching and Learning Environment* (South Africa. Department of Education 2008; South Africa. Department of Basic Education 2010); *Guidelines relating to planning for public school infrastructure* (South Africa. Department of Basic Education 2012); and, a research study by Dr. Candiotes on the provision of schools by the Department of Education and Training (DET) in South Africa from 1983 to 1994 (Candiotes 1997).

2.15.2 The evaluation of school buildings in South Africa

The research done by the DoE (2008) and the DBE (2010) on an enabling school physical teaching and learning environment confirms that the condition of school infrastructure, as well as the learning and teaching environment, are institutional factors that impact on the performance of learners and teachers and that the school buildings being provided lack a sound scientific background and foundation in terms of the building performance and indoor environment quality; this having a negative impact on learners' performance. As previously discussed, research findings reveal that irregular student attendance and dropping out of school, teachers' absenteeism and an inability to engage in the teaching and learning process could be attributed to poor learning physical environments (South Africa. Department of Education 2008, Schneider 2002).

The most recent government report on school infrastructure in South Africa, a National Education Infrastructure Management System (NEIMS) report, found that in 2011 most schools in South Africa did not have the essential physical resources, i.e. classrooms, furniture, toilets, electricity, telephones, etc. needed for quality teaching and learning and that massive backlogs still exist from the years of apartheid (NEIMS 2011). The majority of these schools are primary schools in rural provinces such as the Eastern Cape, KwaZulu-Natal and Limpopo.

According to the School Register of Needs (SRN) (2000) public primary schools constitute a majority of all schooling facilities. The provinces lacking in infrastructure and with the existing infrastructure in poor condition are in the Eastern Cape, KwaZulu-Natal and Limpopo; the least lacking provinces with most of the infrastructure in excellent condition are in the Western Cape and Gauteng.

The NIEMS 2009 and SRN surveys were ground breaking in the "history of education in South Africa as it was the first database that included every school in the country, indicating their geographic location, the condition of buildings and the facilities available" (SRN 2000, SA Department of Basic Education 2009). However, the school condition assessment was limited to a subjective classification of overall school building condition. The overall classification was based on estimates for the condition backlog values and estimated replacement values. This means that various infrastructure elements were assessed according to a specific description for identification purposes, level of service and condition. The condition of elements was assessed on a generic 5-point scale based on the percentage of the element that was in need of refurbishment.

The South African Infrastructure Report Card (SAICE 2011) has rated the public basic education school infrastructure as poor and at risk. The report reveals that the maintenance of education infrastructure in South Africa has been limited, and that this has resulted in conditions deteriorating across all provinces. The report card explains that there is a variation in school infrastructure condition, with urban and ex-Model C schools being generally better maintained than rural schools. The building infrastructure is declared to be unable to cope with demand and to be poorly maintained (SAICE 2011:9).

Summary

In all the surveys, the condition of school facilities was not assessed to the level of building performance nor was post-occupancy evaluation conducted.

2.15.3 **The provision of school buildings in South Africa**

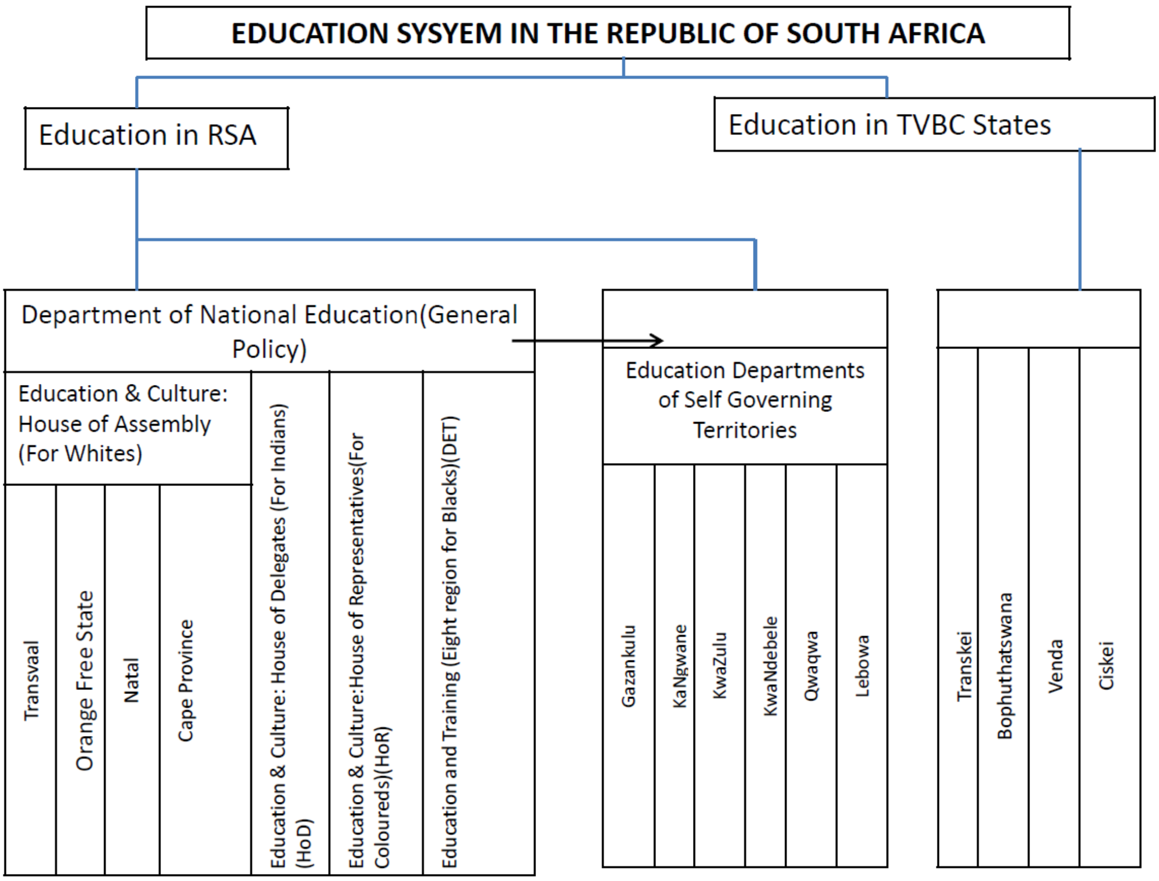
The historical background of education provision in South Africa provides an interesting dimension on how politics and ideology have an impact on the provision of school infrastructure.

Pre-1994 under apartheid there were multiple racially defined departments of education, each of which provided very different types and qualities of education based on the perceived role of that race-group in the apartheid society (Spaull 2012).

Before 1994, South Africa had four provinces: the Transvaal, Orange Free State, Natal and the Cape. Scattered about were also the apartheid "homelands" for black South Africans (southafrica.info) This resulted in several departments of education at national level and provincial level being separated by race; the division of schools and education systems was not only along racial lines but also geographic and socio-economic (Mda & Mothata 2000:45). The apartheid government also based funding for education, education opportunities and curricula according to race. Until 1994 the amount spent per learner in white schools was more than that spent on black students in the urban townships (Fiske and Ladd 2004).

Table 12 below represents the education system in the Republic of South Africa (RSA) pre-1994.

Table 12 Schematic representation of the education system in the Republic of South Africa pre-1994 (Le Roux 2001).



Education was part of the inculcation and maintenance of the apartheid ideology (Spaull 2012) and the allocation of resources, such as school infrastructure and basic services, was the most visible indicator of inequity (South Africa. Department of Education 2008, South Africa. Department of Basic Education 2010).

The majority of black learners were taught in dilapidated and unsafe buildings; their schools had no electricity, safe water, sanitation, telephones or co-curricular facilities and equipment whilst the white learners where taught in well designed and well-resourced facilities (South Africa.Department of Basic Education 2010; HSRC 1981).

Post-1994, racially-defined departments were abolished in favour of nine provincial Departments of Education which operated in collaboration with a single national Department of Education (Spaull 2012).

Although access to education for black learners has improved, the provision of school infrastructure and access to quality facilities for the majority of black learners remains a challenge (South Africa. Department of Education 2008).

2.16 **Primary school buildings in South Africa**

The majority of school infrastructure provision in South Africa exists at the primary school level, where the South African School Act (1996) makes it compulsory for children from seven to fifteen (7 - 15) years old to attend school, from grades one (1) to seven (7). Primary school education is compulsory worldwide because it is perceived as the main driver in achieving global goals such as Education for All (EFA) and the Millennium Development Goals (MDGs) (Statistics South Africa, n.d.)

In 1957, the National Building Research Institute (NBRI) of the Council of Scientific and Industrial Research (CSIR) school buildings committee published a comprehensive report on the planning of primary schools and which lay down design principles for South African primary schools (CSIR 1957). These principles have influenced the design of South African primary schools.

2.16.1 **Primary schools in townships**

The provision of primary schools in townships in South Africa from 1953 to1994 fell under the responsibility of Bantu Administration. From 1994 until 2009 education for all in South Africa fell under the Department of Education. In 2009 the Department was split into two (2) ministries; that is Basic Education and Higher Education and Training (southafrica.info). Thereafter, primary school education fell under the responsibility of the basic education ministry.

Table 13 below shows which administrations were responsible for the provision of school buildings and the legislation that regulated the type of school buildings provided for in townships under the apartheid system and under the unified education system provided by the Department of Education after 1994. The then Transvaal and current Gauteng Provincial administration is used as an example.

Table 13 The provision of schools townships from 1953 to 2010 (by author)

Year	**Administration**		**Department of Education**	**Legislation**	**Agency**
	National	**Provincial**			
1953	Bantu Administration	Local Administration Boards/ Development Boards	Department of Bantu Education	Bantu Education Act 47 of 1953; No building regulations.	Black Local Authorities (BLA)
1980		Department of Training and Education	Department of Training and Education	Education and Training Act 90 of 1979; Cost Norms; Standard Building Regulations (SBR) ; National Building Regulation (NBR).	Department of Training and Education

1994	Department of Education	Gauteng	Department of Education	South African School Act 84,1996; National Education Policy, Act 27 of 1996.	Public Works
1999			Department of Basic Education	SA Constitution; South African School Act 84, 1996; National Building Regulation (NBR) and Building Standards 49 of 1993; South African National Standards (SANS 10400); Occupational Health and Safety Act 85 of 1993; Guidelines relating to planning public school infrastructure (2012)	Gauteng Department of Education (GDE) ; Department of Public Transport, Roads & Works; Gauteng Department of Infrastructure and Development (GDID).

Before 1980, the Department of Bantu Administration was responsible for the erection of school buildings through the employment of Local Administration Boards (Candiotes 1997:18). Local Administration Boards under Black Local Authorities (BLA) operated like municipalities in townships and controlled accommodation, employment and access to the cities (Wittenberg 2003:13) where black people were not allowed to enter and reside without special permission as legislated under the Native Laws Amendment Act of 1952 and Section Ten of the Urban Areas Act of 1952.

Local Administration Boards operated on a regional basis, on a smaller scale than the provinces (Wittenberg 2003:14). The Administration Boards would play a “developmental” role in relation to these municipalities and were accordingly renamed Development Boards. All areas under the Development Boards or townships lacked the commercial and industrial base to finance their activities, thus funds to develop townships were collected from amongst other things, the beer monopoly in townships by the central government and the Native Service Levy by the Development Boards (Wittenberg 2003:14).Therefore, without other funding, funds were low and insufficient, resulting in sub-standard development in townships.

In 1980, after the Education and Training Act 90 of 1979 repealed the Bantu Education Act 47 of 1953, the Department of Education and Training (DET) was responsible for the black population's education. The Directorate: Buildings Services inherited all that came from the Department of Bantu Education and the local Administration Boards (Candiotes 1997:18).

According to Candiotes (1997:18), who was promoted from Principal Architect with the Transvaal Department of Works: School Section to Deputy Director: Building Standards in the Directorate: Buildings of the Department of Education and Training (DET) in 1983, *"...most schools for Blacks had been built by the "Administration Boards" many of them to a standard pattern ..."* shown in the Figure five (5) below.

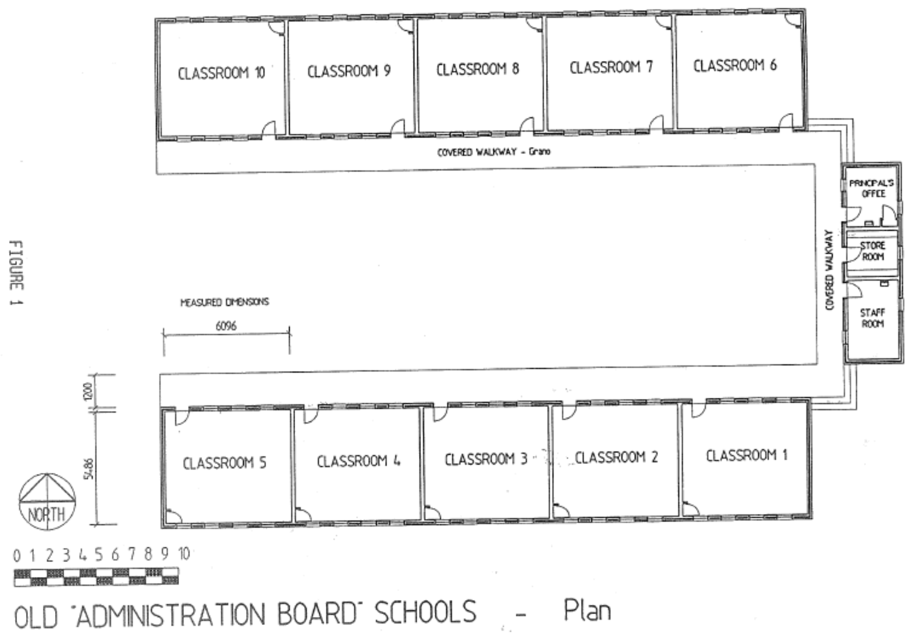


Figure 5 Old "administration boards" schools plan (courtesy of Candiotes 2007)

Candiotes (2007:20-21) further explains that schools built by the Administration Board had a number of challenges such as an absence of school building standards, stating that *"None of the hitherto school buildings were designed to any particular module except that it was common sense that a classroom had to be at least fifty square metre and a general purpose classroom, seventy five square meters ..."* and on thermal performance, energy efficiency and daylighting, "*These aspects, being foreign to the functionaries pre-1983, were not specifically considered in anyway whatsoever.*"

Candiotes (2007:22) also points out the chaotic process that was part of school provision by the Administration Board, such as irregularities in appointing consultants, who in most cases were not building professionals, and the lack of monitoring in the building of schools process.

2.16.2 **Apartheid years: 1983-1994 (Provision of schools by DET)**

The Department of Education and Training (DET) was established to cater for schools that do not fall within the boundaries of homelands (e.g. that instead are found in townships) and was established in terms of the Education and Training Act, Act 90 of 1979 (Republic of South Africa 1979) which was implemented in 1980.

The DET built primary schools and secondary schools using standards designs whose restrictions and limitations were predetermined by the schedule of accommodation for all teaching institutions dictated by the "Space and Cost Norms" for all Government buildings introduced by the Government, under the auspices of the State Treasury Department (Candiotes 2007:24).

The standard designs for new primary schools for the DET were based on tried and tested standards used by the Transvaal Provincial Administration (TPA) school building agency, Transvaal Department of Works: School section. The DET appointed private architects as principal agents to execute the architectural services of a school for the DET.

The TED / TPA primary school standards were adopted by the DET and according to Candiotes are still used today as the basic standard primary school. The adopted design layout that influenced future design types for DET primary school buildings was the Mayville Primary School shown in figure six (6) below.

This design was an updated version of the Waterkloof Primary School, developed by the National Building Research Institute (NBRI) of the Council of Scientific and Industrial Research (CSIR). The difference between the NBRI (CSIR) standards and the TED / TDA is the minimised acceptable cost through the reduction of total floor area (Candiotes 2007:24, Appendix A).

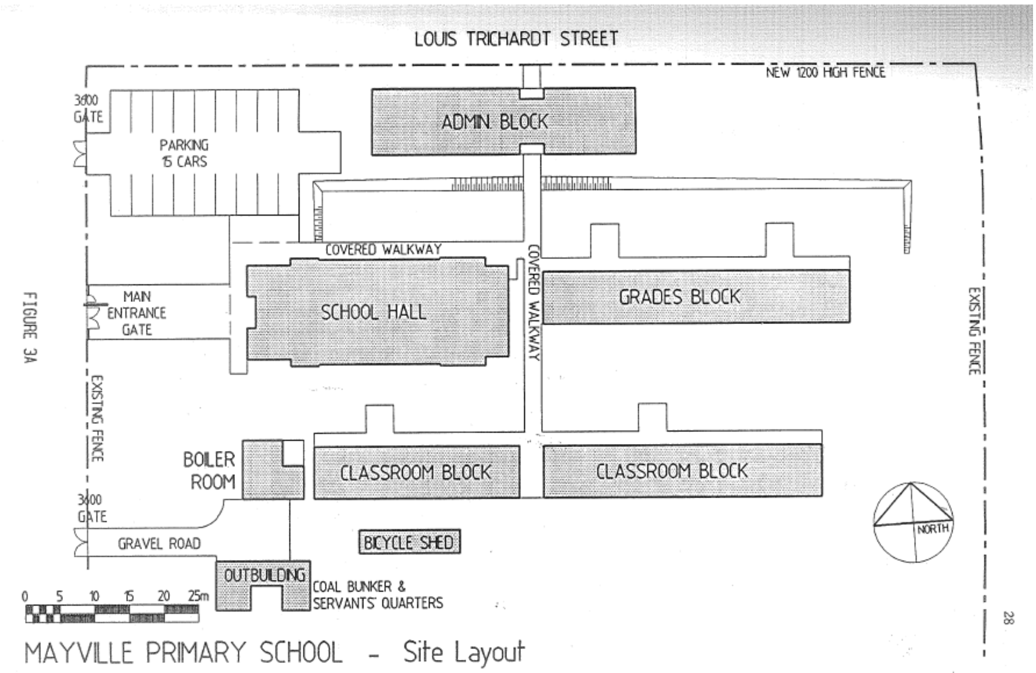


Figure 6 Mayville primary school (courtesy of Cadiotes 2007)

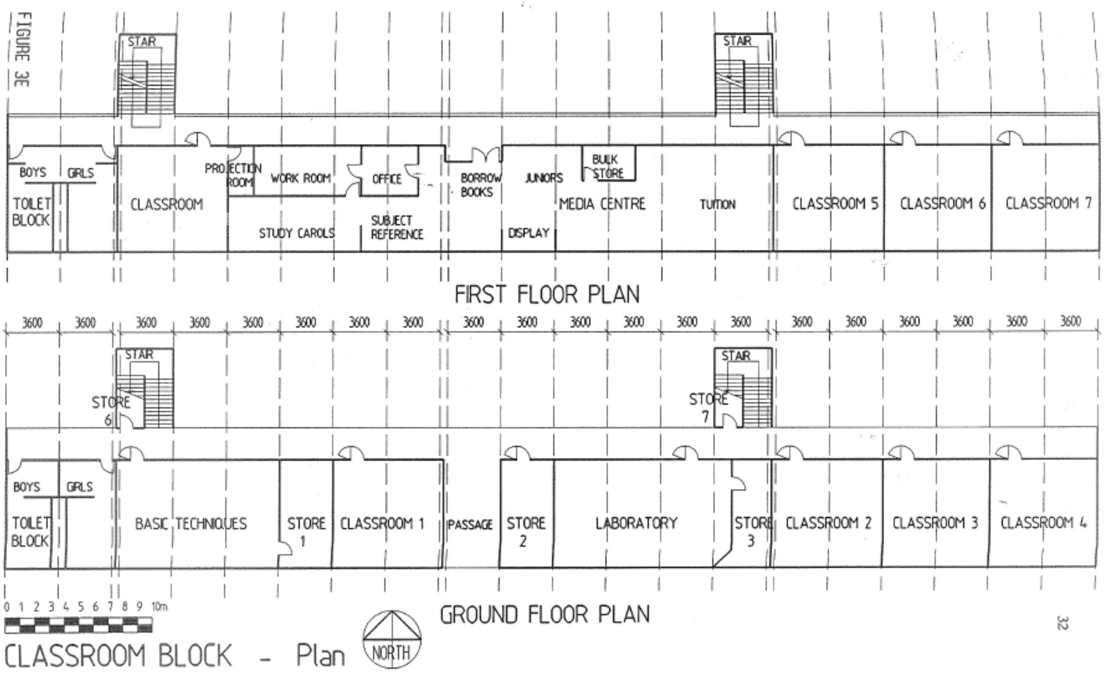


Figure 7 Typical classroom block (courtesy of Candiotes 2007)

In the design of a standard classroom, the learners' welfare was considered as an important factor. The learner ratio was decided by teaching authority to be thirty-five (35) learners to one (1) teacher, but to allow for overcrowding the standard classroom was planned to accommodate forty (40) learners. The module of 3 600mm was established as the most suitable and cost effective, determining the depth / length of classroom to be two modules which are 7 200mm centre to centre of wall. This results in the width of classrooms being 6 980mm or 7 000mm for easy reference. The total floor area hence becomes forty-nine (49) m^2, the "Norm" being fifty (50) m^2 (Candiotes 2007:34) (see figure eight (8) below).

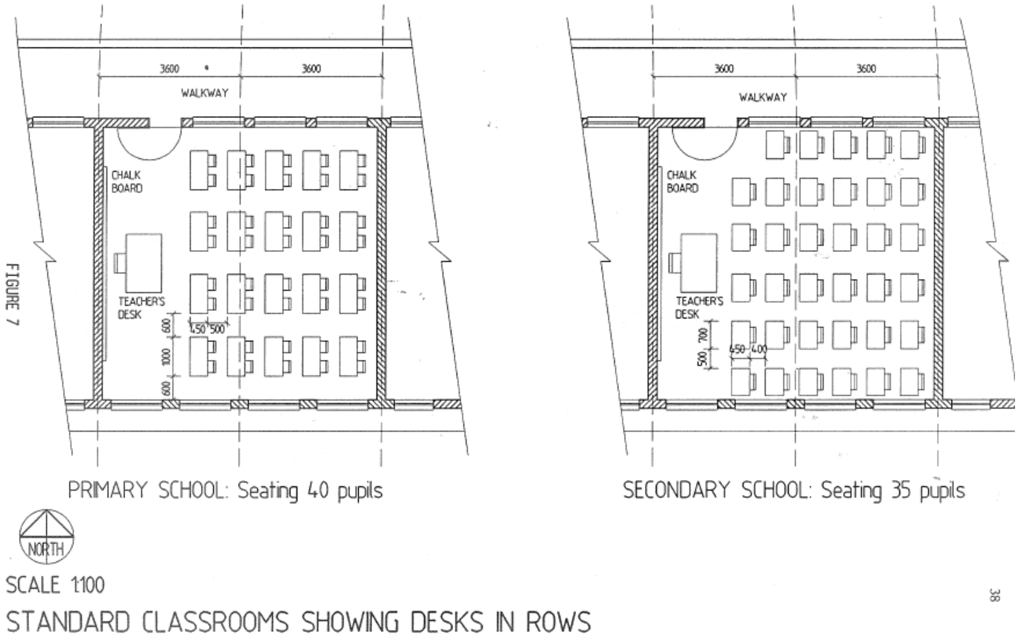


Figure 8 Standard classroom – drawing not to scale (courtesy of Candiotes 2007)

Standard Building Regulations (SBR) and National Building Regulations (NBR) were used in the development of primary school standards.

Final standards for primary schools for DET were finalised in 1986.The design details and layouts could be configured into a variety of configurations (Candiotes 2007:72).The three (3) final types of design configurations are shown in figures nine (9) to eleven (11) below.

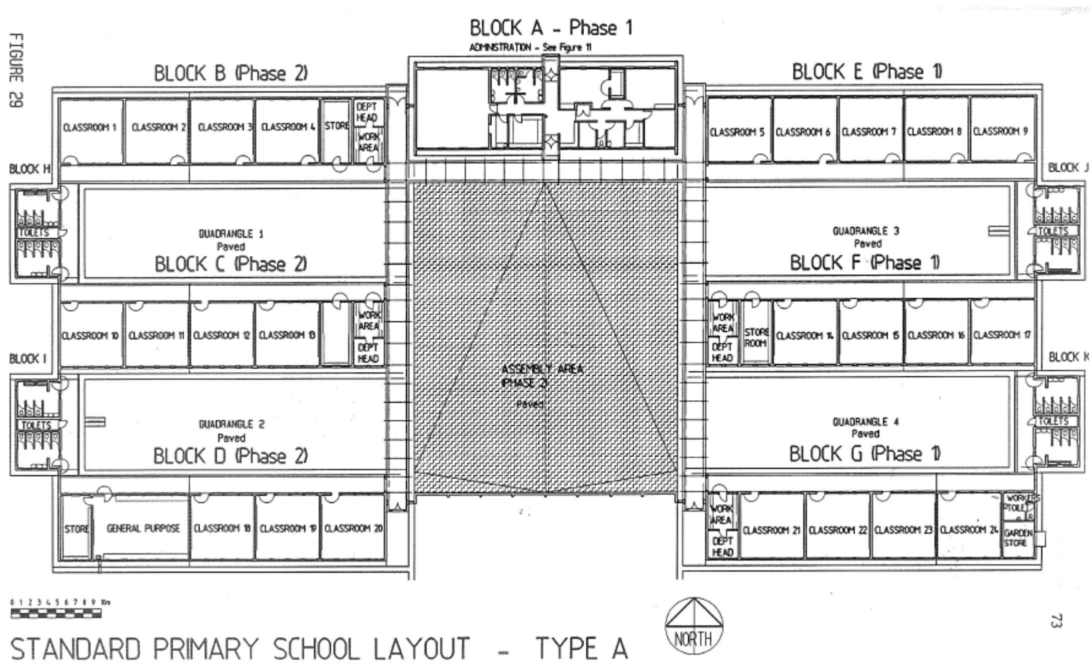


Figure 9 Standard primary school layout – type A (courtesy of Candiotes 2007)

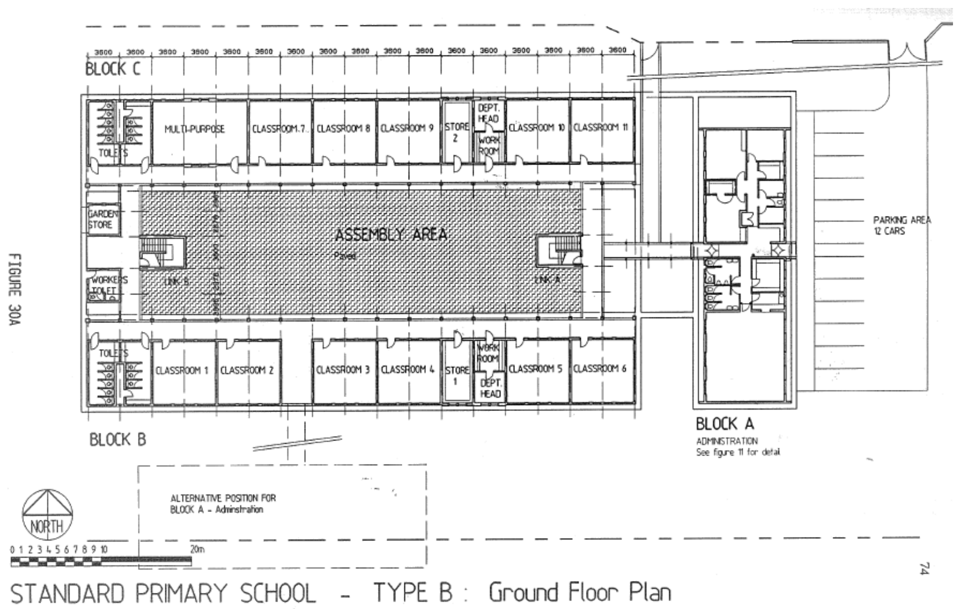


Figure 10 Standard primary school layout – type B (courtesy of Candiotes 2007)

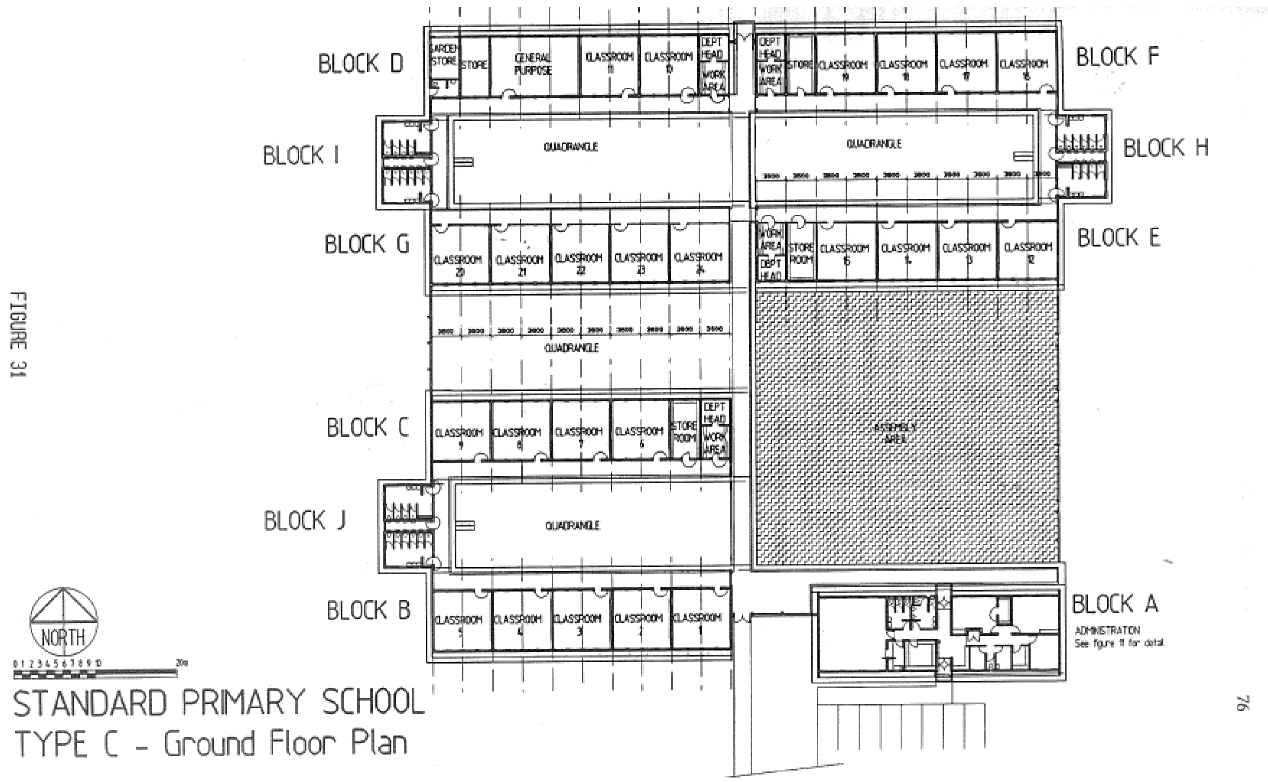


Figure 11 Standard primary school layout – type C (courtesy of Candiotes 2007)

2.17 **Summary**

Primary school buildings in South African township vary in design and size. This variation was influenced by the availability of funds, research and the legal framework driven by politics and socio-economic issues. Research by the CSIR (1957) and Candiotes (1997) has influenced the design of public primary schools in South Africa.

The findings of this research on the primary school types, layouts and designs influence the development of the LTCP. Generic plans of classrooms can be made prior to conducting field studies.

2.18 **Climatic data**

The climate plays an important role in impacting on thermal conditions which influence building design, building construction, health, adaptive behaviour and culture.

South Africa has six climatic zones as described in the SAN 204:2011 (see table 14). The City of Tshwane (COT) fall under the climatic zone two (2), described as the temperate interior (see figure 12 & table 14). Weather data for COT was recorded by the Pretoria Forum weather station, located at latitude 25.733° South and longitude 28.183°, at Greenwich time. The COT temperature range is shown in table 15 and figures 13 and 14 below.

Table 14 South African climatic zones

Zone	Description	Major centre
1	Cold interior	Johannesburg, Bloemfontein
2	Temperate interior	COT/Pretoria, Polokwane
3	Hot interior	Makhado, Nelspruit
4	Temperate coastal	Cape Town, Port Elizabeth
5	Sub-tropical	coastal East London, Durban, Richards Bay
6	Arid interior	Upington, Kimberley

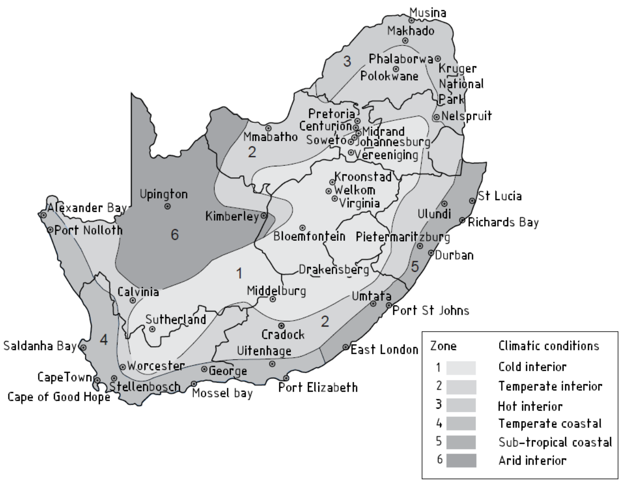


Figure 12 South African climatic zones (SANS 10400:xa)

Table 15 The COT temperature range

Temperature range				
Annual average high temperature	±25°C			
Annual average low temperature	±13.5°C			
Average high temperature	September	±26°C	October	±29°C
Average low temperature		±12°C		±16°C
Recorded high	September	±31°C	October	±33°C
Recorded low		±6°C		±11°C
Monthly mean - September	±19°C			
Monthly mean - October	±21°C			
Summer comfort zone	±20.5 - 26°C			
Winter comfort zone	±20.5 - 24.5°C			
Relative humidity	50%			

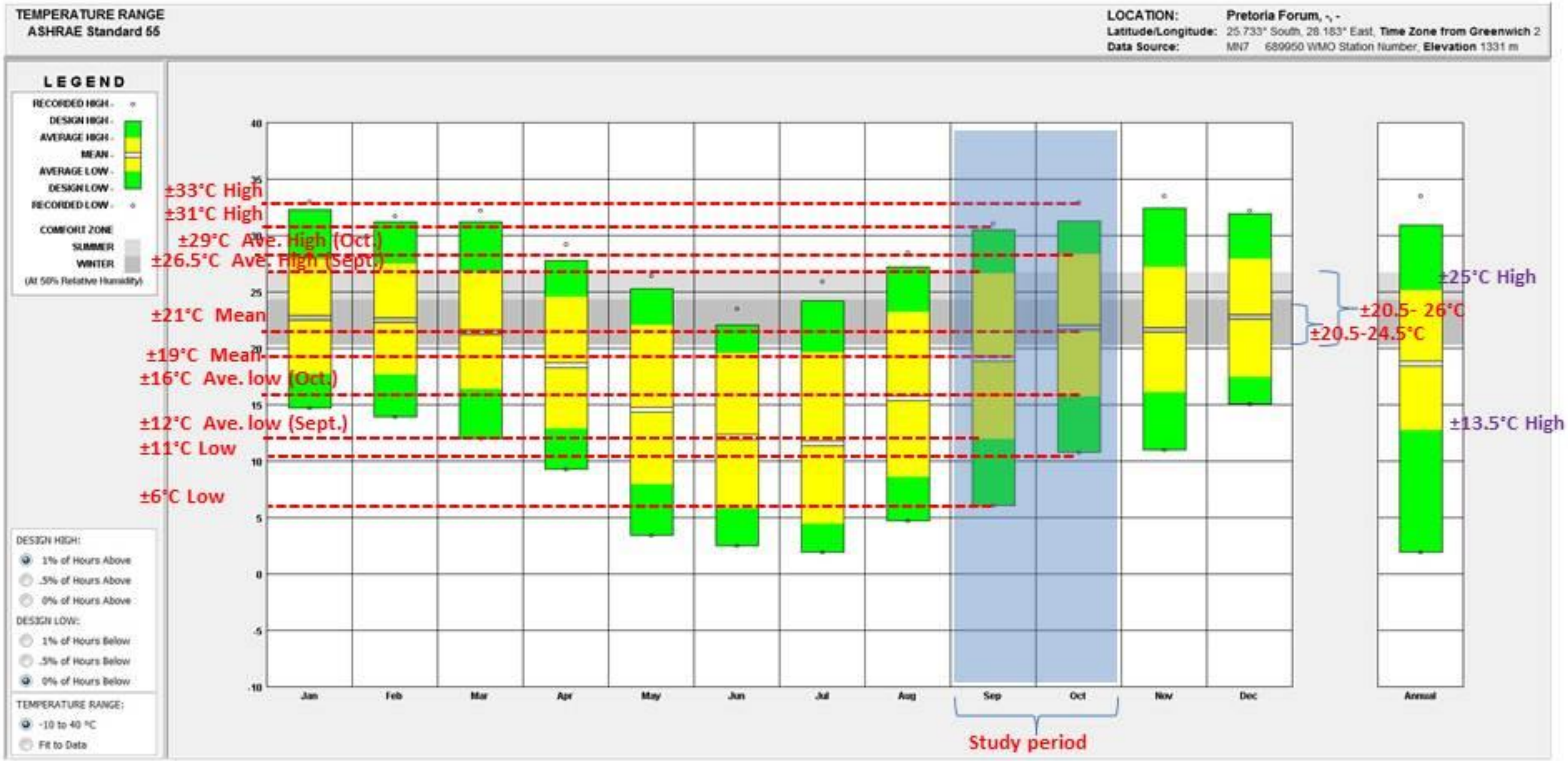


Figure 13 Pretoria temperature range

WEATHER DATA SUMMARY

LOCATION: Pretoria Forum, -, -
Latitude/Longitude: 25.733° South, 28.183° East, **Time Zone from Greenwich** 2
Data Source: MN7 689950 WMO Station Number, **Elevation** 1331 m

MONTHLY MEANS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
Global Horiz Radiation (Avg Hourly)	501	482	462	410	396	376	399	456	508	511	511	525	Wh/sq.m
Direct Normal Radiation (Avg Hourly)	412	412	428	407	561	616	619	611	568	521	463	442	Wh/sq.m
Diffuse Radiation (Avg Hourly)	208	195	181	165	106	85	89	105	137	164	178	204	Wh/sq.m
Global Horiz Radiation (Max Hourly)	1217	1181	1126	951	806	727	780	912	1075	1182	1219	1242	Wh/sq.m
Direct Normal Radiation (Max Hourly)	1087	1077	1064	1019	986	965	974	997	1041	1041	1083	1082	Wh/sq.m
Diffuse Radiation (Max Hourly)	545	522	479	422	360	315	317	347	451	506	535	552	Wh/sq.m
Global Horiz Radiation (Avg Daily Total)	6732	6219	5600	4668	4255	3928	4236	5086	6035	6464	6775	7134	Wh/sq.m
Direct Normal Radiation (Avg Daily Total)	5545	5312	5174	4622	6010	6427	6558	6800	6747	6580	6131	6003	Wh/sq.m
Diffuse Radiation (Avg Daily Total)	2796	2531	2205	1893	1144	888	945	1181	1629	2079	2371	2772	Wh/sq.m
Global Horiz Illumination (Avg Hourly)	55634	53412	51067	45132	43006	40610	42764	48939	54571	55560	55925	57975	lux
Direct Normal Illumination (Avg Hourly)	39505	39922	41339	38538	53698	58742	59257	58595	55165	50491	45099	42652	lux
Dry Bulb Temperature (Avg Monthly)	22	22	21	18	14	12	11	15	19	21	21	22	degrees C
Dew Point Temperature (Avg Monthly)	15	15	14	11	5	4	0	2	4	9	12	14	degrees C
Relative Humidity (Avg Monthly)	66	66	65	65	58	61	49	45	41	49	59	63	percent
Wind Direction (Monthly Mode)	80	70	80	300	290	290	290	310	50	90	70	70	degrees
Wind Speed (Avg Monthly)	1	1	0	0	0	0	0	1	1	1	1	1	m/s
Ground Temperature (Avg Monthly of 1 Depths)	19	20	20	20	19	18	17	16	16	16	17	18	degrees C

Study period

Figure 14 Weather data summary: means monthly

3 Identification of pertinent issues

Three pertinent issues that have been identified from the previous chapters are as follows:

1) The suitability of predictive thermal comfort models for determining acceptable thermal conditions in naturally conditioned or ventilated buildings located in warm/hot climates;
2) The suitability of the methods for evaluating learners' (aged 9 - 14 years) thermal acceptance, neutrality and preference;
3) Concepts that can be drawn from the thermal comfort standards in the development of a Learner Thermal Comfort protocol.

3.1 Issue 1

In reviewing thermal comfort standards for the development of the Learner Thermal Comfort Protocol the following issues must be considered: the scope of standards; the characteristics of school buildings; and, learners' adaptive limitations. These constraints address issue 1.

ISO Standards 7730 (2005), ASHRAE Standard 55 and CEN Standard EN 15251 are criticised for not being applicable to regions with warm / hot and humid climates because they were developed based on theoretical analyses of human heat exchange performed in mid-latitude climatic regions in North America and northern Europe (Djongyang et al 2007).

However, the thermal comfort standards' scope states clearly the limitations regarding the use of the standards. For instance, the ASHRAE 55-2004 Standard does not contain data on evaluating environments occupied by children in their scope, but suggests that the information in the standards could be applied *'judiciously to groups of occupants such as are found in classroom situations*'. The ASHRAE 55-2004 Standard is meant to be used for environments occupied by healthy adults for more than 15 minutes.

The ISO Standard 7730 (2005) is also specifically developed for the work environment occupied by healthy adults and is intended to be used with other ISO standards (i.e. ISO/TS 14415:2005) when considering persons with special requirements. However, when applying the standard on non-conditioned spaces ethnic, national or geographical differences need to be taken into account (ISO Standard 7730-2005).

As discussed, when assessing thermal comfort in school environments it must be considered that school environments have unique characteristics when compared to adult work environments. Learners are often engaged in a range of activities in more densely occupied rooms, with limited opportunities to adapt their uniforms and operate any environmental controls to meet their thermal preferences (Zhang et al 2007,Teli et al 2012, de Dear et al 2014).

Literature research on thermal comfort in warm climates confirm that learners (children and adults) in warm climates have a higher heat tolerance and accept thermal conditions which exceed the standard of between 26°C and 28°C, but cooler thermal sensations are preferred (Wong & Khoo 2002,Kowk& Chun 2003, Hwang et al 2006, Appah-Dankyi & Korateng 2012, Liang et al 2012).

3.2 **Issue 2**

The investigation of the suitability of the PMV thermal comfort models in predicting learners' (aged 9 - 14 years) thermal acceptance, neutrality and preference in naturally ventilated buildings (ter Mors 2010), revealed that improving the methods used to determine insulation and metabolism can improve the accuracy and quality of PMV based predictions for children. Taking into account the physiological variations and psychological effects which are excluded in the PMV model could improve the assessment of thermal comfort, especially in naturally ventilated spaces.

3.3 Issue 3

The development of a Learner Thermal Comfort Protocol (LTCP) requires concepts to be drawn from the thermal comfort standards, then adapted and adopted for them to be applied in classroom environments.

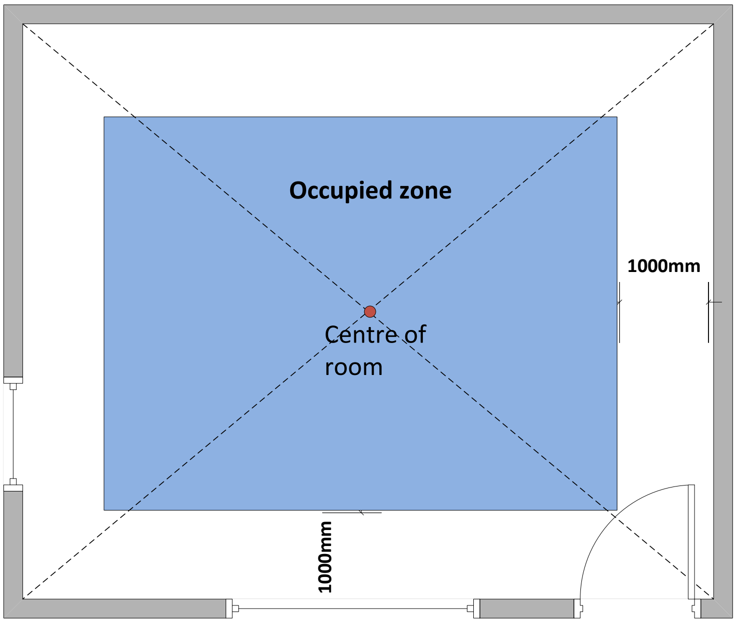
The concepts drawn from thermal comfort standards are:

i. **The occupied zone**
ii. **Radiant asymmetry**
iii. **Vertical air temperature difference**
iv. **Thermal insulation of clothing**
v. **Activity**
vi. **7 point scale thermal sensation scale**
vii. **Adaptive thermal comfort chart/model.**

Table 16 Thermal comfort standards concepts

Concepts	ISO Standards 7730 (2005)	ASHRAE 55-2004
Aim: To determine area of measurement		
The occupied zone (plan view) ***The occupied zone (sitting or standing)*** ***Air temperature***	For mechanical system: The operative temperature at all locations within the occupied zone of a space should at all times be within the permissible range. This means that the permissible range should cover both spatial and temporal variations, including fluctuations caused by the control system.	For mechanical system: If occupancy distribution cannot be estimated, then the measurement locations shall be as follows: (a) In the centre of the room or zone. (b) 1.0m inward from the centre of each of the room's walls. In the case of exterior walls with windows, the measurement location shall be 1.0m inward from the centre of the largest window. *Air temperature* Taken at the ankle level (0.1m), the waist level (0.6m), and the head level (1.1m), for seated occupants, Taken at ankle (0.1m), waist level (1.1m), and head level (1.7m) for standing occupants. As shown in figure 15.
Aim: To determine thermal discomfort: ceiling & walls		
Radiant asymmetry	Percentage dissatisfied (PD) for warm ceiling / wall determined by equations e.g.:	*Warm ceiling* must not be more than 5°C of actual temperature *Cool ceiling* must not be more than 14°C than actual temperature

	a) Warm ceiling $$PD = \frac{100}{1 + \exp(2{,}84 - 0{,}174 \cdot \Delta t_{pr})} - 5{,}5$$ $\Delta t_{pr} < 23\ °C$	*Warm wall* must not be more than 23°C than actual temperature *Cool wall* must not be more than 10°C than actual temperature
Aim: To determine thermal discomfort: head & feet		
Vertical air temperature difference	Vertical air temperature difference between the feet and the head.	Vertical air temperature difference between the feet and the head should not exceed 3°C of actual temperature. Refer to comfort zone figure 15 (sitting and standing position).
Aim: To determine thermal insulation (clo):		
Thermal insulation of clothing	PMV related (clothing insulation values included in standard)	Thermal insulation not required for Adaptive thermal comfort model. For conditioned spaces (Static model): 0.5clo (warmer temperatures) and 1.0clo (cooler temperature).
Aim: To determine the metabolic rate of occupants		
Activity	PMV related (activity level values included in standard)	For conditioned and non-conditioned spaces (Static model and Adaptive model) : Occupants must be engaged in near sedentary physical activity (with metabolic rates between 1.0 met and 1.3 met) (clothing insulation values included in standard)
Aim: To measure thermal sensations		
7 point scale thermal sensation scale	ASHRAE thermal sensation scale. See table 1	ASHRAE thermal sensation scale. See table 1.
Aim: To determine thermal comfort acceptability through relation of internal temperature to external temperature		
Adaptive thermal comfort chart / model	To determine acceptable operative temperature according to standard, clothing insulation value that responds to the local clothing habits and climate shall be used.	There are 2 operative temperature limits: 1) 80% acceptability and 2) 90% acceptability. Model only applies when mean outdoor temperatures are more than 10°C and less than 33.5°C (See figure 1).



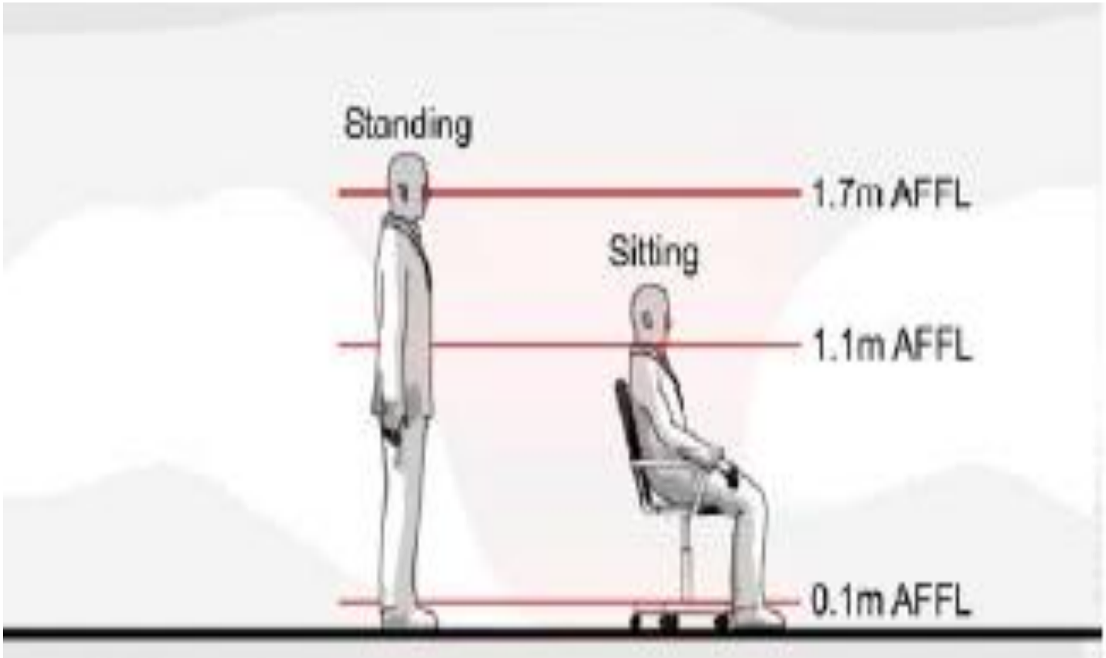


Figure 15 The occupied zone – plan view above (by author) and sitting or standing position (below) for the ISO 7730 (source: Chilled Beams & Ceiling Association (CBCA))

3.4 Developing the Learner Thermal Comfort Protocol (LTCP)

Table 17 Learner Thermal Comfort Protocol development

Concepts Adopted	**Adaptation of standard for Learner Thermal Comfort Protocol**
Aim: To determine area of measurement :	
The occupied zone (plan view) **The occupied zone (sitting or standing)** **Air temperature**	*The occupied zone is not required for the Adaptive thermal comfort model used for thermal comfort assessment in naturally conditioned buildings but has been adopted and adapted for the LTCP.* ASHRAE 55-2004 measurement locations adaptation: Occupied zone defined as area 600mm away from centre of inside wall. Actual air temperature is the average temperature of the air surrounding an occupant. See figure 16. Measurement of actual air temperature: i. Internal: T1 - T10 ; T1 - T9 fall within the occupied zone, T10mmost likely to fall outside the occupied zone - T1 - T9 located on learners desks at height ranging between 575 - 650mm - T10 located on teacher’s desk at height of +-725mm. ii. External: T11 located outside to measure outside temperatures. iii. Two central loggers to measure the temperature near the ceiling and temperature near the feet.
	Reason for adaptation i. Occupied zone is extended to be 600mm away from wall, as to capture air temperature of learners close to wall. ii. Internal location of measurements at T1 - T10 aim to capture air temperature at the desks located at the sides and centre of classroom. Air temperatures will be related to learners’ perception. iii. The external air temperature (T11) captures the outside temperature to assess the effect of external temperature on the internal temperature. iv. T1 - T9 located on learners’ desks at height ranging from 575 – 650mm and T10 located on teacher’s desk at height of +-725mm. Location of measurements determined by primary school furniture heights (See table 11 and figures 17 & 18).

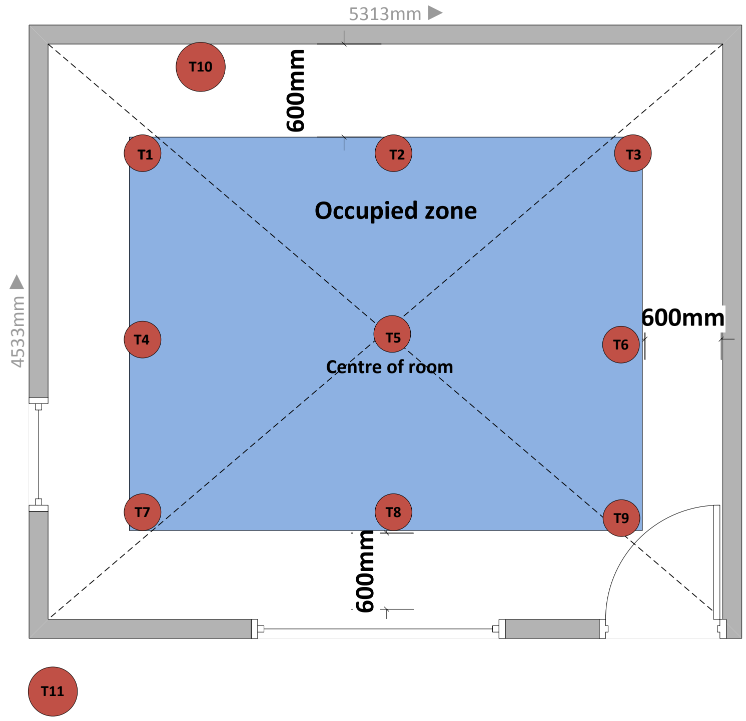


Figure 16 Location of measurements within comfort zone

Aim: To determine thermal discomfort: ceiling & walls

Radiant asymmetry

Radiant asymmetry is not required for the Adaptive thermal comfort model used for thermal comfort assessment in naturally conditioned buildings but has been adopted by LTCP.

Warm ceiling must not be more than 5°C.
Cool ceiling must not be more than 14°C.

Measurement of radiant temperature taken at ceiling centre, see figure 17.
Radiant temperature from wall not taken.

Aim: To determine thermal discomfort: head & feet

Vertical air temperature difference

Vertical air temperature is not required for the Adaptive thermal comfort model used for thermal comfort assessment in naturally conditioned buildings but has been adopted and adapted by LTCP.

Vertical air temperature difference between the feet and the head should not exceed 3°C of actual temperature.
Vertical temperature difference taken at centre of room (see plan in figure 16 and section in figure 17) at:

- feet area by securing data logger at the table leg at levels between 100 - 150mm from finished floor level (see figure 18),
  head area (sitting) by securing data logger at desk centre, 575 – 650mm (see figure 17)
- Head area standing not taken to avoid learners playing with logger when hanging from ceiling.

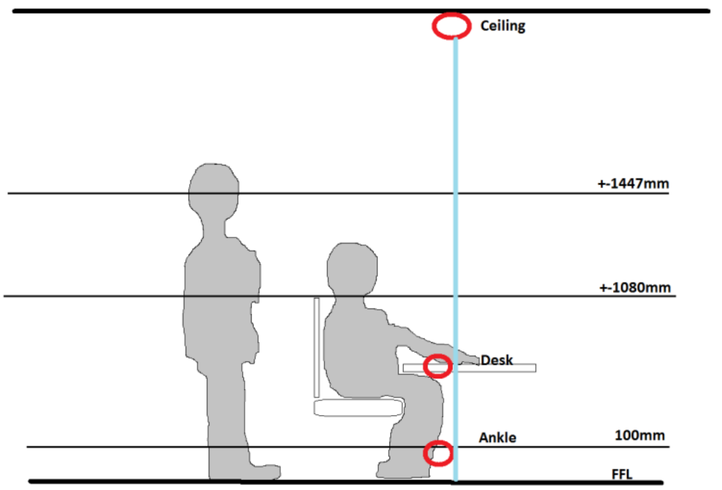
<table>
<tr>
<td></td>
<td>Air temperature around the head area – will use data logger information on central table.
Refer to tables 10 & 11 for school learner heights and furniture heights.


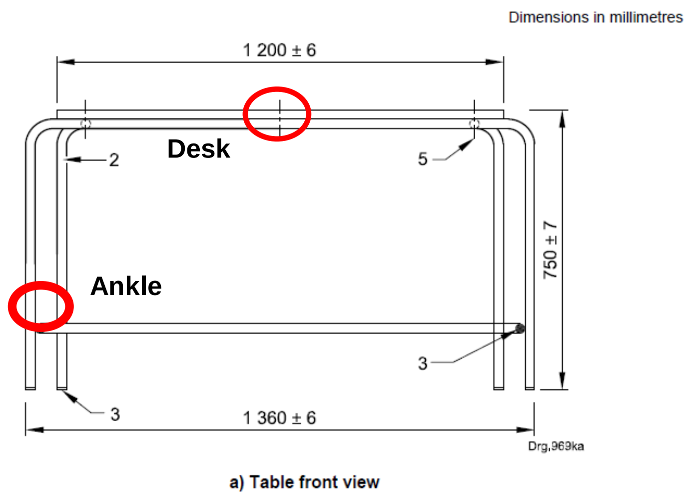
Figure 17 Vertical temperature difference at centre of room (by author)


Figure 18 Location of loggers at learner desk (SANS 660:2013)</td>
</tr>
<tr>
<td></td>
<td><u>Reason for adaptation</u>

Height of air temperature measurement adapted to measure air temperature at the learners' height.</td>
</tr>
<tr>
<td colspan="2"><u>Aim: To determine thermal insulation (clo)</u></td>
</tr>
<tr>
<td>Thermal insulation of clothing</td>
<td>Thermal insulation is not required for the Adaptive thermal comfort model used for thermal comfort assessment in naturally conditioned buildings but has been adopted and adapted by LTCP.

Thermal insulation was taken to relate learners' thermal sensation responses with what they are wearing (thermal insulation):
- ASHRAE 55 clothing values adopted;</td>
</tr>
</table>

<table>
<tr><td></td><td>- Thermal insulation is recorded on questionnaire.</td></tr>
<tr><td colspan="2"><u>Aim: To determine learner activity</u></td></tr>
<tr><td>Activity</td><td>Activity / metabolic rate is not required for Adaptive thermal comfort model used for thermal comfort assessment in naturally conditioned buildings but has been adopted and adapted by LTCP.

The occupants are engaged in near sedentary physical activity (with metabolic rates between 1.0 met and 1.3 met).</td></tr>
<tr><td colspan="2"><u>Aim: To determine learner thermal sensation</u></td></tr>
<tr><td>7-point thermal sensation scale</td><td>The ASHRAE thermal sensation scale (see table 1) has been adopted and adapted to measure 5-points of learner thermal sensation.

Table 18: 5-point scale LTCP thermal sensation scale
<table>
<tr><th>Description</th><th>Number</th><th>Satisfaction</th></tr>
<tr><td>Hot</td><td>2</td><td>Unsatisfied</td></tr>
<tr><td>Warm</td><td>1</td><td rowspan="3">SATISFIED</td></tr>
<tr><td>Neutral</td><td>0</td></tr>
<tr><td>Slightly cool</td><td>-1</td></tr>
<tr><td>Cold</td><td>-2</td><td>Unsatisfied</td></tr>
</table></td></tr>
<tr><td colspan="2"><u>Aim: To determine learner thermal comfort acceptability</u></td></tr>
<tr><td>Adaptive thermal comfort chart / model</td><td>ASHRAE 55 adaptive thermal comfort chart for the assessment of thermal comfort acceptability in naturally conditioned spaces has been adopted by LTCP. See figure 1 for chart.
In order to assess the acceptable indoor temperatures in classrooms using the Adaptive model in this study, the City of Tshwane (CoT) mean monthly outdoor air temperatures are used. The likely temperature range for CoT in September, with the monthly mean temperature at 19°C, is ±20.1°C - ±27°C and will achieve 80% occupant acceptability; whereas ±21°C - ±26.2°C will achieve 90% occupant acceptability. For October the monthly mean temperature is 21°C and temperatures ranging from ±21°C - ±27.8°C will achieve 80% occupant acceptability and temperatures ranging from ±22°C - ±27°C will achieve 90% occupant acceptability (See figures 45 & 46).</td></tr>
</table>

3.5 Application of the Learner Thermal Comfort Protocol (LTCP)

3.5.1 Learner Thermal Comfort Protocol tools

Tools required for the collection of thermal comfort data (see Addenda A) were:

- Letters of consent;
- School building data form;
- Field work protocol;
- Questionnaires; and,
- Data loggers (12 per class and 1 outside).

3.5.2 Procedures followed in data collection

STEP 1

Identify sample
- Identify school to be studied
- Identify the participants for the study

STEP 2

Obtain research approval & consent
- From the Department of Basic Education (DBE)
- From the research ethic department
- From the school & participants

(See addenda A: Letters of consent - Section 10.3)

STEP 3

Collect information
- Survey the classroom and fill out school building data form (see addenda A – School building data form)
- Map classroom layout and locate where learners sitting (A, B or C sections) including teacher's desk (see addenda A – Field work protocol: quantitative data 1).
- Identity comfort zone and position data loggers on desks – T2 - T10 see addenda A – Field work protocol: quantitative data 2)
- Position central loggers at the central table lower leg and the other close to the ceiling
- Distribute age appropriate questionnaires to learners with approved consent

STEP 4

Analyse data and Interpret the results

4 Research Methodology

4.1 Research design framework

Table 19 Research design framework

Philosophical

Worldviews

Positivist

Research

Design

<u>Testing of LTCP</u>

Quantitative method

Descriptive research

Selected strategies of

enquiry

Quantitative strategies

Descriptive research method :

Survey: Close ended questionnaires

Longitudinal study

Research methods

Questions: what is?

Data Collection

Data Analysis

Interpretation

Write-up

Organizes, tabulates, depicts, and describes the data collection

4.1.1 **Philosophical worldview: Positivist**

A positivist worldview was chosen so that the research hypothesis can be tested via a controlled collection of data from learners, educators and the environment.

4.1.2 **Selected strategies of enquiry**

A quantitative strategy of enquiry which is a structured method of data collection was used. Although the data collection methods are controlled, the environment is not. The learner and educators were studied in their classroom environment in order to observe their behavioural responses. The quantitative process allows the research to be objective, replicable and to be carried out on a large scale.

4.1.3 **Research design**

In the evaluation thermal comfort in township primary school classrooms, this study followed the descriptive research method which aimed at finding out *"what is"* the condition in the classrooms. Structured survey methods (i.e. close-ended questionnaires) were used to collect descriptive data. Through descriptive research, data was gathered so that thermal comfort data could be described and organized / tabulated and depicted. The descriptive research used visual aids such as graphs and charts to aid the reader in understanding the data distribution. A longitudinal study was carried out on the selected schools and classrooms to yield more reliable results.

4.1.4 **Research methods**

4.1.4.1 Sources of data

i. Documents

The documents required were design plans from the selected schools and classroom designs, along with the building specification. The plans and building specifications are required to analyse and understand the building structure and to mark positions where readings will be taken and map occupancy (furniture and furniture use – desk / table layouts and seated students).

ii. Observation

The classroom layout plans form part of the observation and analysis. Using plans enables mapping patterns of seating arrangements, learner activity and behaviour and captures how the teacher controls the environment (opening / closing of windows).

4.1.4.2 Instruments: Questionnaires and data loggers

The instrument that was used to collect the quantitative data from learners and teachers were indoor environment assessment questionnaires. The students and teachers / educators were requested to fill in questionnaires once, preferably towards the end of the week and 30 minutes before the end of the school day.

Other instruments that were used to collect the quantitative data were HOBO U12_012 standalone data loggers; these are electronic devices that record indoor temperature, relative humidity and light levels data over time by means of built-in sensors. The data loggers are small, battery powered, portable, equipped with a microprocessor and have internal memory for data storage.

The data loggers were programmed to automatically record and were left unattended to collect data at the same time during teaching hours for a week at the schools. This allowed for a comprehensive, accurate picture of the environmental conditions being monitored.

This approach simultaneously reduced the resource, time and cost challenges that were seen as limitations of the project. For example:

i. the need for extra manpower to complete the study on time;

ii. increased manpower and training cost;

iii. human errors that may occur while taking measurements.

Risk factors such as device theft and failure were considered and influenced the positioning and securing of devices.

The data was collected from the devices every day after school or at the end of seven days.

The instruments were not intended to interrupt teaching nor distract learners from their regular behaviours or daily program.

4.2 Data analysis

4.2.1 Quantitative data analysis

The questionnaires for the foundation phase and intermediate phase learners employed the Likert Scale to rank responses. The scales range from 'least' to 'most', asking learners to indicate how much they agree or disagree, approve or disapprove. The scales were given a numerical value for analysis purposes, i.e. 0 is an ok or acceptable condition and -2 / 2 is the most uncomfortable.

Data was downloaded on a daily basis from the data loggers onto a laptop on site, or in some cases after seven days of continuous recording. The collected data was then analysed using Microsoft Excel and captured in graphs.

4.3 Ethical issues

Ethics approval was required for this study as it involved human participants who may be affected by the research. The rights of the individuals giving data have been considered and the information they provided has been treated in a sensitive manner. All data remains confidential and respondents were assured that their anonymity would be maintained.

The research received ethical approval from the University Research Ethics committee as well as consent from the Gauteng Department of Education (GDE), the schools, learners and parents. The benefits of the research, responsibilities and privacy issues were included in the consent forms.

The research received permission from the GDE and Gauteng Department of Infrastructure Development (GDID) to allow access to documentation and drawings relating to the selected case studies.

4.4 Research Sample

Purposive sampling was used in the selection of schools, classroom and participants (as mentioned in Chapter 2).

4.4.1 Sample group

4.4.1.1 Selection of schools

The selection of schools for the evaluation was limited to the Pretoria area, Region 6, Mamelodi suburb (see figure 19). Mamelodi Township in the City of Tshwane (CoT) falls under zone two (2) of the six (6) climatic zones in South Africa and is categorised as a temperate interior region (SANS 10400-XA: 2011) (see figure 12 & table 14). The area in which the schools are located are high density formal and informal settlements (see figure 20).

Two building types were selected for the study, that is the traditional brick and motar (high thermal mass in Case study A) and light weight steel construction in Case study B (see figures 21 & 22).

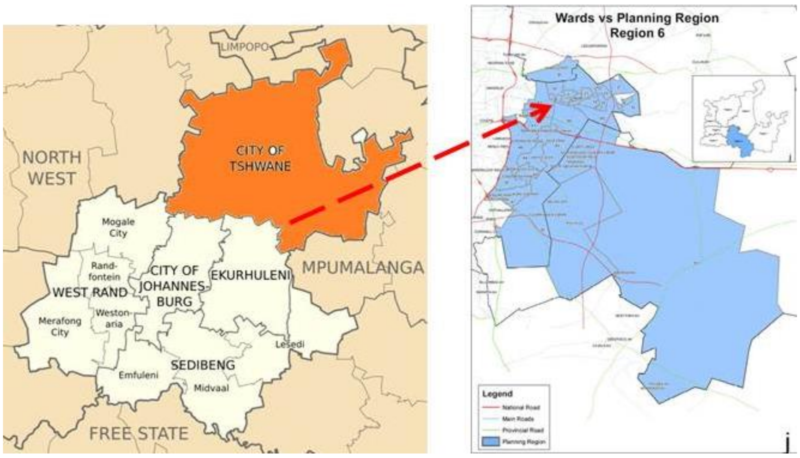


Figure 19 City Of Tshwane – Ward 6 (COT maps & GIS 2013)

FIGURE 20 Locations of schools in Mamelodi (courtesy of google maps 2014)

Figure 21 Location of Botlhabatsatsi primary school in Mamelodi west, arial photograph (courtesy of Google earth 2012)

Figure 22 Location of the Meetse-a-Bophelo and Legora primary school in Mamelodi east, arial photograph (courtesy of Google earth 2012)

The selected schools are:

i. Botlhabatsatstsi primary school - Mamelodi West, built in1959 by the Black Local Authority (Case study A)

ii. Meetse-A-Bophelo primary school – Mamelodi East, built in 2010 by the Gauteng Department of Education in partnership with ArcelorMittal South Africa (Case study B)

See table 20 below for school building summary

Table 20: School building information summary

Building Information	***Schools***	
	Botlhabatsatsi primary school (A)	**Meetse-a-Bophelo primary school(B)**
Condition & Age	Good, 55 years Built 1959	Very Good, 4 years Built 2010
Occupancy :	60%; some classes not used	Overcrowded; built to accommodate 1 200 learners
Class size :	Average 49 m^2	*(Varies)* average of 60 - 72+ m^2
Learner teacher ratio:	1:30	1:60+
Building configuration:	Linear blocks	Multiple blocks - wings at angles (“star” configuration)
Building type :	Standard brick construction, built by Black Local Authorities	Steel construction – Built through public private partnership of DBE and ArcelorMittal Foundation
Courtyard:	Yes – one central	Yes -multiple
Ventilation Type:	Natural ventilation	

4.4.1.2 Sample size

One classroom was selected according to the following phases: Foundation phase (grade 3); Intermediate phase (grades 4 to 6); and, Senior phase (grade 7).

This study estimated that questionnaires from an average of 40 students per grade would be collected. This number is based on the number of students per classroom. The Norms and Standards recommend 40 children per ordinary school classroom with a sitting space of 1.2 m^2 - 1.5 m^2 per child. Under normal circumstances there is crowding in South Africa schools, hence the number of learners participating in the study was predicted to increase depending on the school and classroom occupation.

This gave predicted results of an average number of 120 students and 3 teachers per school completing the indoor environment assessment questionnaire. In total, 360 learners were given questionnaires to complete and 8 classrooms were assessed.

The collection of data / field study took place in summer in the selected schools and the analysis of data took place thereafter.

5 Analysis and interpretation of data

The Learner Thermal Comfort Protocol (LTCP) was used to collect data for the case studies A and B so that it could be tested.

5.1 Case study A: Botlhabatsatsi primary school

Figure 23 Location of school and classrooms, arial photograph (courtesy of Google earth 2013)

Botlhabatsatsi primary school's 2013 statistics show that there were a total of 274 learners attending the school. This classifies Bothlabatsatsi primary school as a small to medium primary school, where there can be one to two classes per grade (see addenda B). Bothlabatsatsi primary school has one class per grade. The selected classrooms for this study are classrooms for grade 3 with an occupancy of 31 learners, grade 5 with an occupancy of 31 learners, grade 6 with an occupancy of 28 learners, grade 7 with an occupancy of 37 learners. In total 127 learners were expected to participate in this study.

Bothlabatsatsi primary school faces north east. The grade 3 classroom is located north west of the site and Grades 5, 6 &7 are located on the south west of the school site. The classrooms are in linear blocks, surrounded by open space / courtyards allowing for sufficient ventilation.

5.1.1 Grade 3: 09/09/2013 - 13/09/2013

Actual temperature data for grade 3 classrooms was collected for a week from 9 September to 13 September 2013 from 08:00 to 14:00. Refer to addenda B for actual desk air temperature measurements.

Figure 24 below show the location of air temperature data loggers in the grade 3 classroom, for the measurement of the actual air temperature.

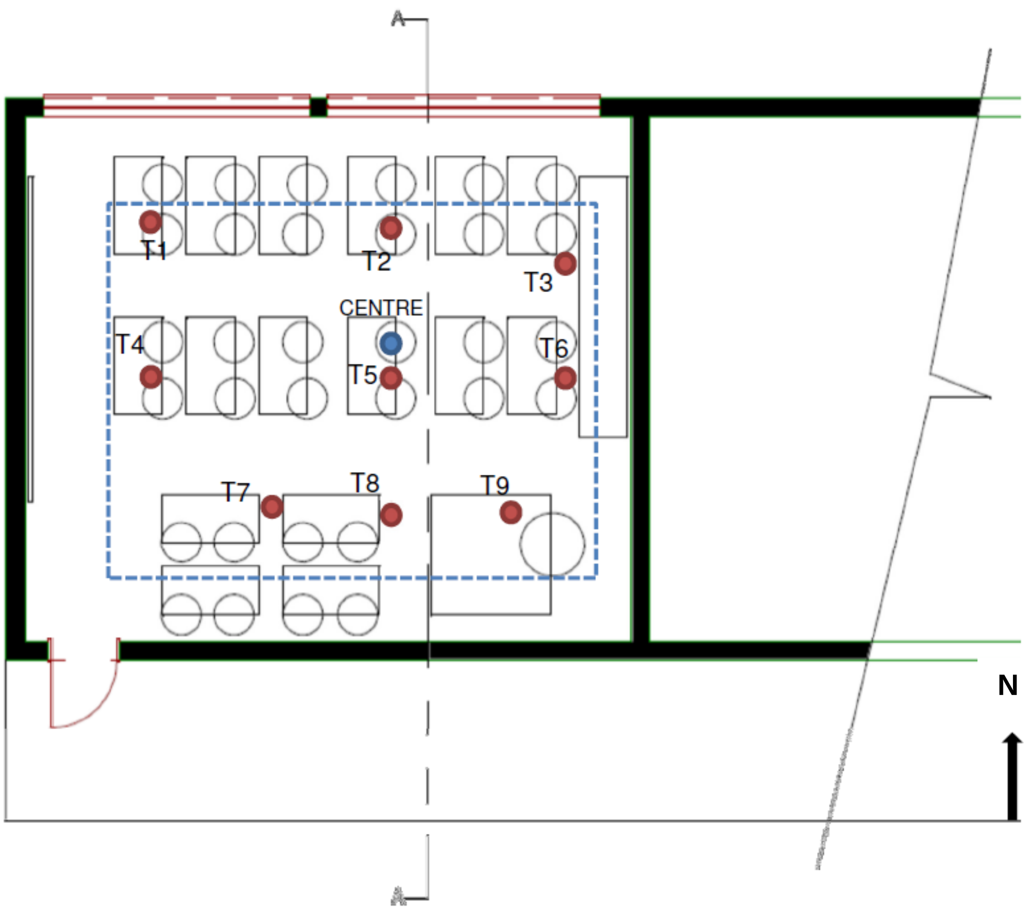


Figure 24: Location of loggers

Table 21 Grade 3 classroom temperature averages

Average temperatures at desks	09/09/2013	10/09/2013	11/09/2013	12/09/2013	13/09/2013	Average
Ave. Min. temp	18.9	22.6	21.8	22.5	22.1	21.58
Ave. Max. temp	30.7	33.4	32.1	31.2	31.5	31.78

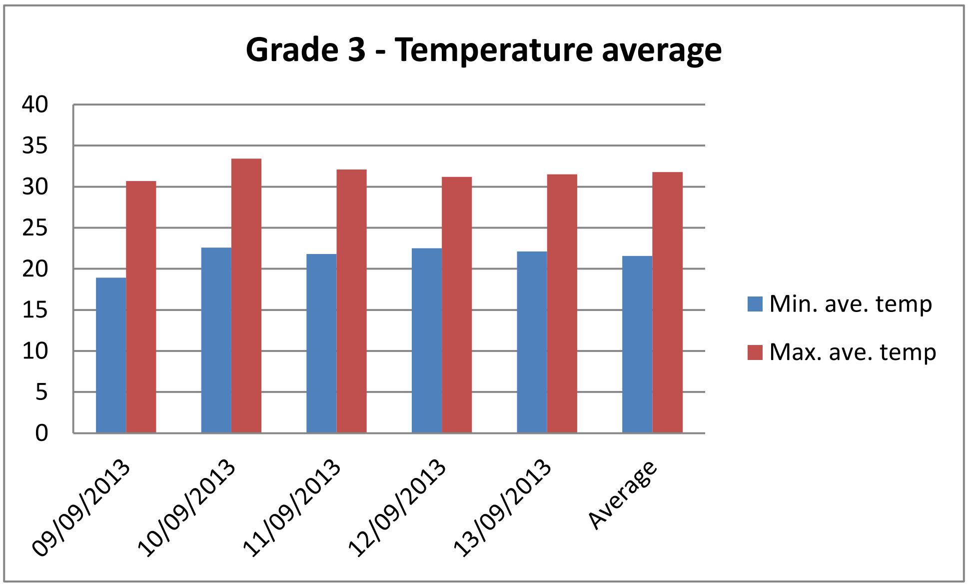


Table 21 shows that the average minimum and maximum temperature for grade 3 classrooms taken from 9 September 2013 to 13 September 2013 between 08:00 and 14:00 ranged from 21.6°C to 31.8°C.

5.1.1.1 Discussion

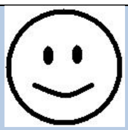
The average internal air temperature experienced by the grade 3 learners ranges from a minimum of 21.6°C to a maximum of 31.8°C. The average minimum temperatures are within the recommended range by the thermal comfort standards; however, the average maximum temperature is 4.5°C greater than the recommended temperature, i.e. 22°C to 27°C . These average maximum temperatures occur in the afternoon before school ends. The minimum temperature occurs in the mornings. The air temperature in the classroom increases gradually throughout the day.

High temperature ranges were recorded from the T1-T3 loggers with temperature ranges from 35°C to 44.1°C. These temperatures exceed the recommended temperatures by 8°C to 17°C.

5.1.1.2 Learners' perception of thermal comfort

To measure the learners' perception of the thermal comfort, the grade 3 learners were asked to respond to two statements; that is 'MY CLASSROOM IS HOT' and 'MY CLASSROOM IS COLD' through selecting one of five faces that described agreement or disagreement with the statement. The five faces represent five scales but **<u>do not</u>** represent satisfaction as such; the scales of 1, 0, -1 represent satisfaction. See table 22 below.

Table 22 Learner perception scale

Face	Description	Scale	Sensation		
			HOT: MY CLASSROOM IS…	COLD: MY CLASSROOM IS…	
	I strongly agree	2	HOT	COLD	
	I agree	1	WARM	COOL	Satisfaction
	It is Ok	0	**OK** (NOT HOT / COLD)	**OK**	
	I disagree	-1	COOL	WARM	
	I strongly disagree	-2	COLD	HOT	

The classroom was divided into three sections for the location of learners to assess close proximity to walls / windows. In this classroom these were: Section A – close to a wide low window facing North; Section B – the middle; and Section C close to the wall with high small window openings (see figure 25 below).

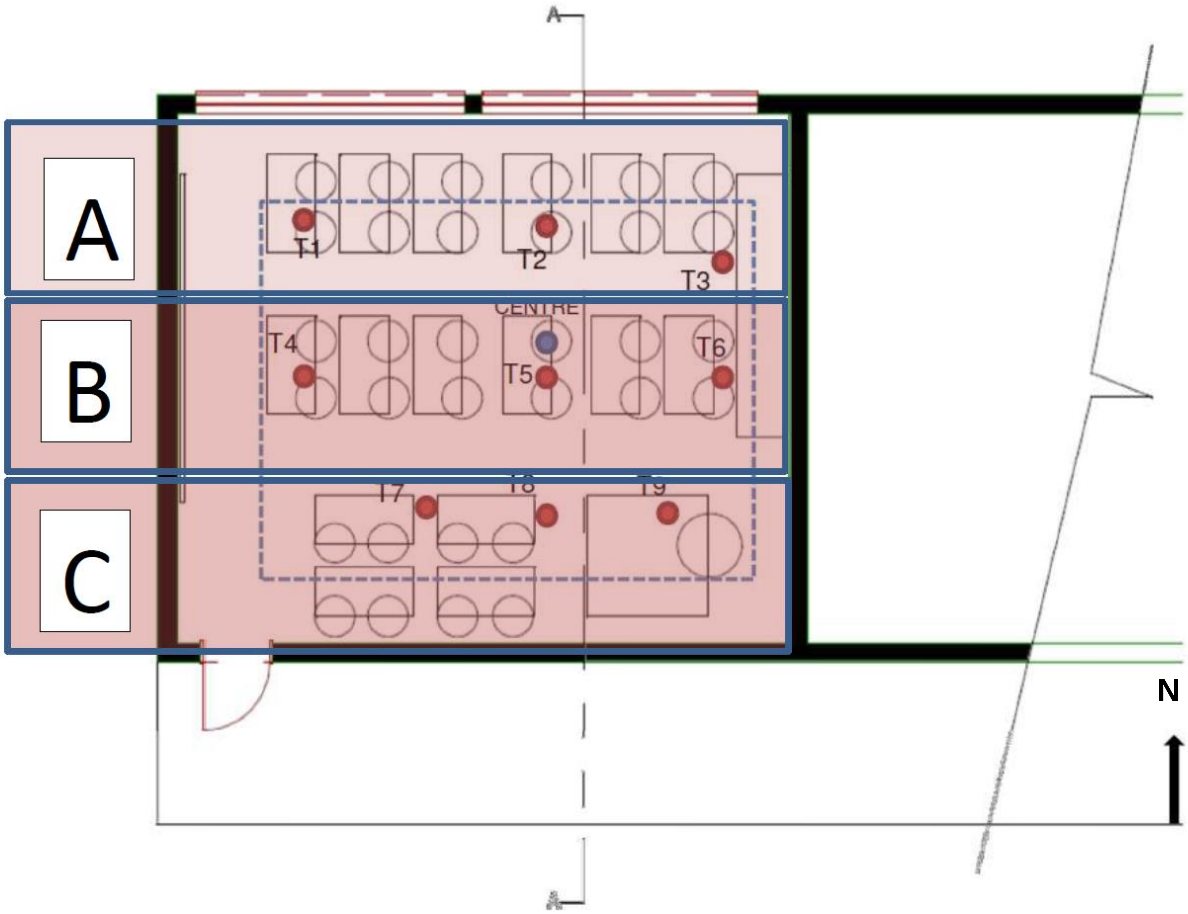


Figure 25 The 3 sections of the classroom

A – Close to the large windows, B – Middle of classroom, C – Close to wall with high small windows

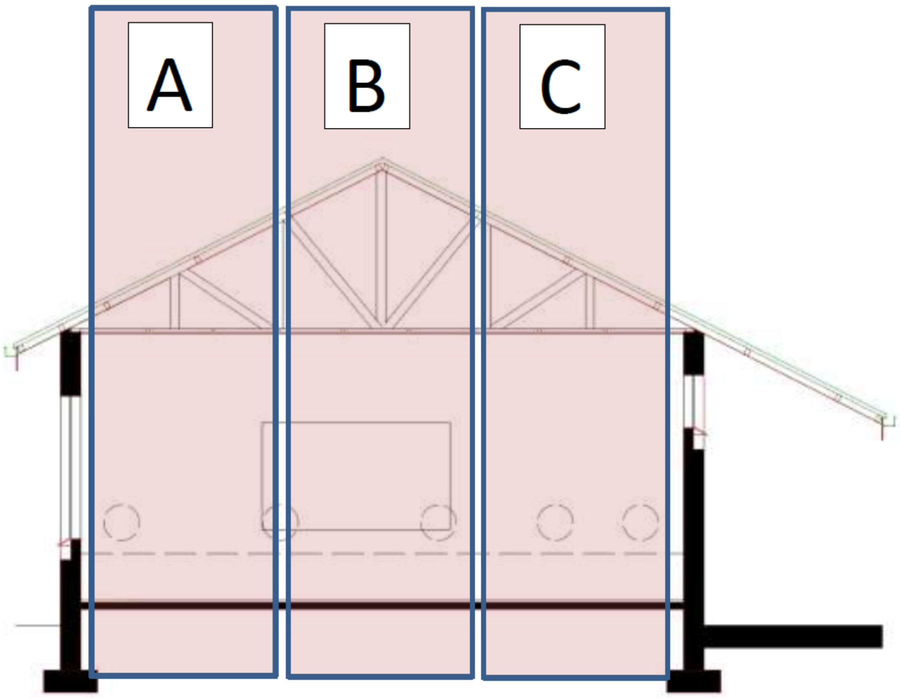


Figure 26 Section of the grade 3 classroom

Table 23 Thermal sensation response to 'MY CLASSROOM IS HOT' statement (13/09/2013)

Section A		**Section B**		**Section C**	
Sensation scale	***No. of Students***	***Sensation scale***	***No. of Students***	***Sensation scale***	***No. of Students***
2	4	2	-	2	4
1	2	1	-	1	1
0	4	0	6	0	1
-1	2	-1	3	-1	-
-2	2	-2	-	-2	1
	14		**9**		**7**

Table 23 shows the responses of the 30 learners that participated in the survey taken on the afternoon of 13 September 2013 (13:30-14:00).

Section A: 4 learners strongly agreed that they were hot, 2 learners agreed that they were hot, 4 learners were OK and 4 learners disagreed with the statement.

Section B: 6 learners were OK and 3 learners disagreed with the statement.

Section C: 4 learners strongly agreed that they were hot, 1 learner agreed that he or she was hot, 1 was OK and 1 learner disagreed with the statement.

Table 24 Thermal sensation response to 'MY CLASSROOM IS COLD' statement

Section A		Section B		Section C	
Sensation scale	***No. of Students***	***Sensation scale***	***No. of Students***	***Sensation scale***	***No. of Students***
2	1	2	2	2	2
1	-	1	-	1	1
0	5	0	5	0	4
-1	3	-1	-	-1	-
-2	-	-2	2	-2	-
	9		**9**		**7**

Table 24 shows the responses of the 25 learners that participated in the survey taken in the afternoon on 13 September 2013.

Section A: 1 learner strongly agreed that he or she was cold, 5 said they were OK and 3 disagreed that it was cold.

Section B: 2 learners agreed it was cold, 5 learners were OK and 2 disagreed that it was cold.

Section C: 3 learners agreed it was cold and 4 were OK.

Table 25 Learner perception of hotness of the classroom (13/09/2013)

Comfort level	Students
-2	3
-1	3
0	11
1	3
2	8
(blank)	2
Grand Total	**30**

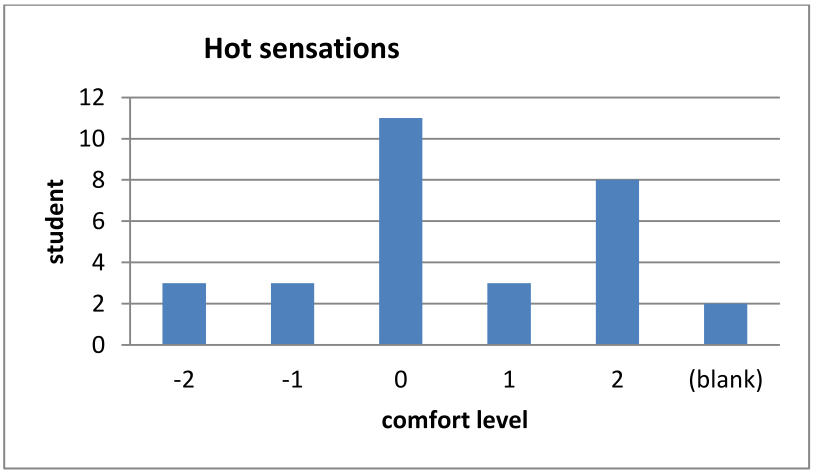


Table 25 shows that on 13 September 2013, 11 out of 30 learners in grade 3 agreed that the classroom was hot, 11 learners felt that the classroom was OK, 6 learners disagreed that the classroom was hot.

It is assumed that the 60% (17 out of 28) of learners that voted -1, 0 and 1 were satisfied with the thermal conditions.

Table 26 Learner perception of coolness of classroom

Comfort level	Student
-2	2
-1	3
0	14
1	1
2	5
(blank)	5
Grand Total	**30**

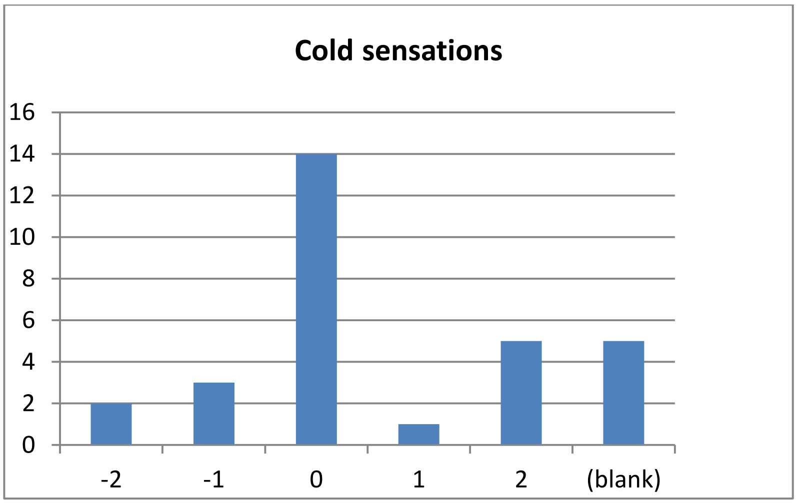


Table 26 shows that out of the 30 learners that participated in the study, 14 learners expressed neutrality to the coldness of the classroom, 6 agreed that it was cold and 5 disagreed that it was cold. It is assumed that the 72% (18 out of 25) of learners that voted -1, 0 and 1 were satisfied with the thermal conditions.

Table 27 Learner clothing insulation in relation to perception of hotness in classroom

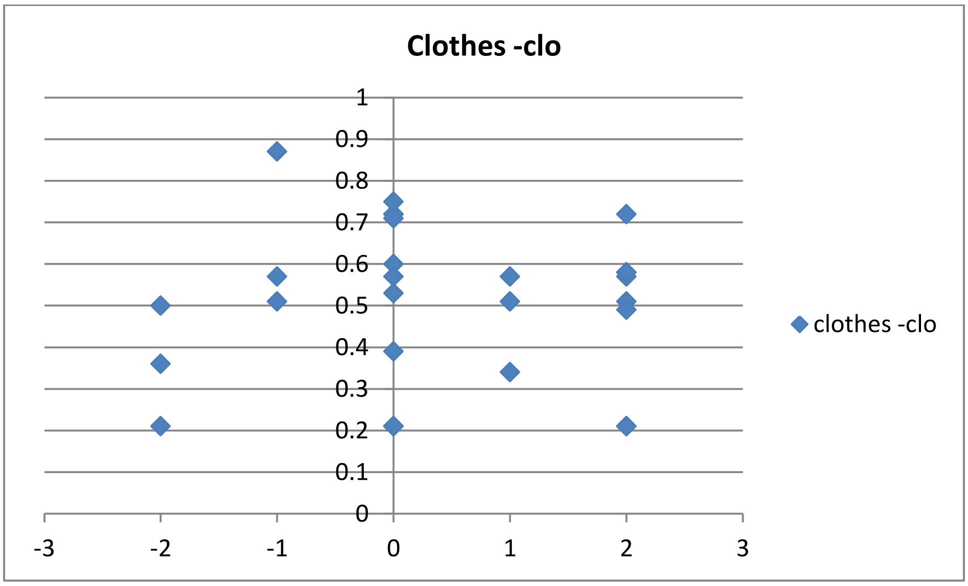
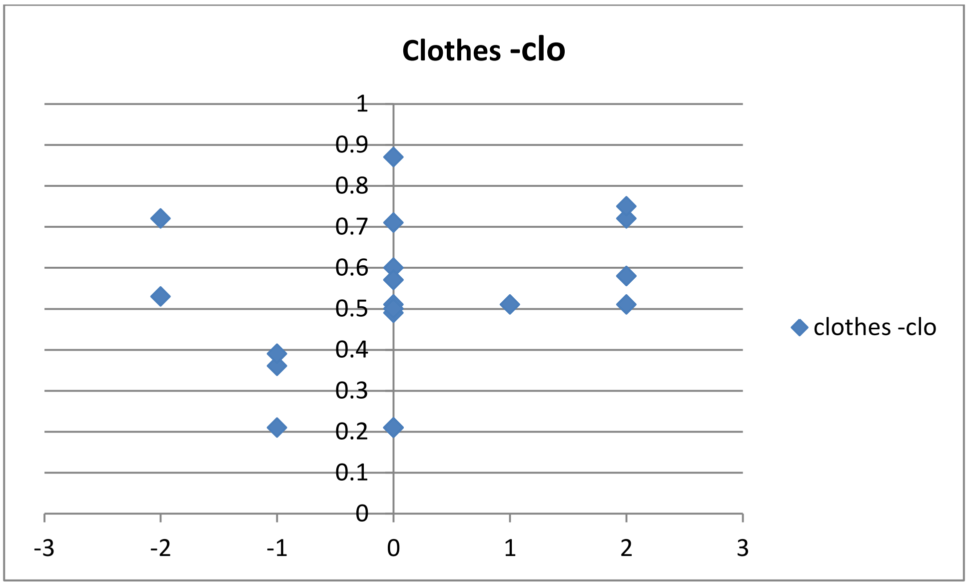


Table 28 Learner clothing insulation in relation to perception of coldness of the classroom



Tables 27 and 28 show that the linear correlation is near zero, meaning that no relationship exists between what the learners are wearing and their thermal sensations.

The majority of learners dressed within the clothing insulation range of 0.21 to 0.75clo expressed neutrality with the thermal environment. Therefore, clothing insulation did not influence learners' thermal sensation.

5.1.1.3 Discussion

The perception survey of heat in the grade 3 classroom shows that most of the grade 3 learners felt that the classroom was hot; this is especially reflected by the learners seated in section A (Desk T1 - T3). This perception corresponds with the high temperatures recorded. Only four (4) out of thirty (30) learners felt that it was not hot and 5 felt it was not cold – maybe they felt it was warm and cool. However, it is assumed that a high percentage of the learners that voted -1, 0 and 1 were satisfied with the thermal conditions.

5.1.2 Grade 5: 09/09/2013 - 13/09/2013

Actual temperature data for grade 5 was collected for a week – 9 September to 13 September 2013 – from 08:00 to 14:00. Refer to addenda B for actual desk air temperature measurements.

Figure 27 below shows the location of air temperature data loggers in the grade 5 classroom, for the measurement of the actual air temperature.

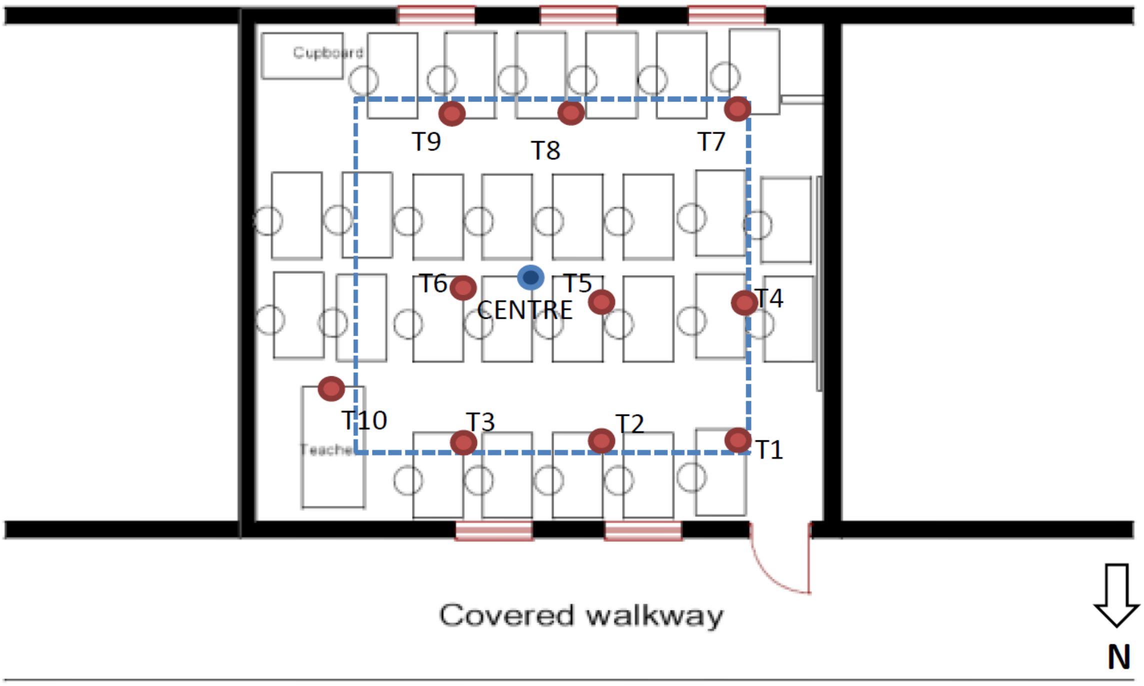


Figure 27 Location of loggers

Table 29 Grade 5 classroom temperature averages

Average temperature at desks	09/09/2013	10/09/2013	11/09/2013	12/09/2013	13/09/2013	Average
Ave. min. temp	17.83	20.8	20.1	21.5	21.2	**20.286**
Ave. max. temp	27.59	27.8	28.7	26.5	29.06	**27.93**

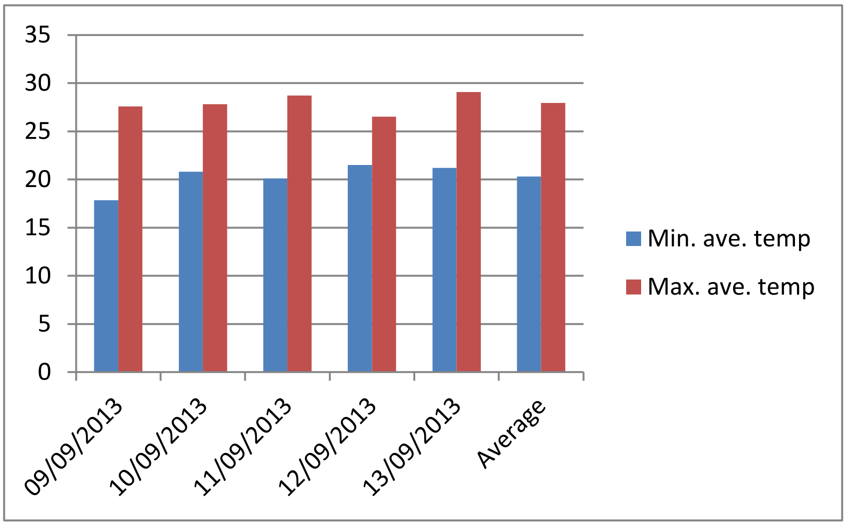


Table 29 shows the average minimum and maximum temperatures in grade 5 from 9 September 2013 to 13 September 2013; this ranged from 20.3 to 27.9°C between 08:00 and 14:00.

5.1.2.1 Discussion

The average internal air temperature experienced by the grade 5 learners ranges from a minimum of 20.3°C to a maximum of 27.9°C. The average minimum is within the range recommended by the thermal comfort standards (i.e 22°C to 27°C) and maximum temperatures are slightly above. The average maximum temperatures occur in the afternoon before school ends and the minimum temperature occur in the mornings. The air temperature in the classroom increases gradually throughout the day. However, the minimum temperature falls below recommendations and the maximum temperature is above the recommendations.

The maximum temperatures were recorded in the middle of class and ranged from 28°C to 29°C.

No perception survey was taken for this class owing to learners' unavailability.

5.1.3 Grade 6: 09/09/2013 - 13/09/2013

Actual temperature data for grade 6 was collected for a week from 9 September to 13 September 2013 from 08:00 to14:00. Refer to addenda B for actual desk air temperature measurements.

Figure 28 below shows the location of air temperature data loggers in the grade 6 classroom for the measurement of the actual air temperature.

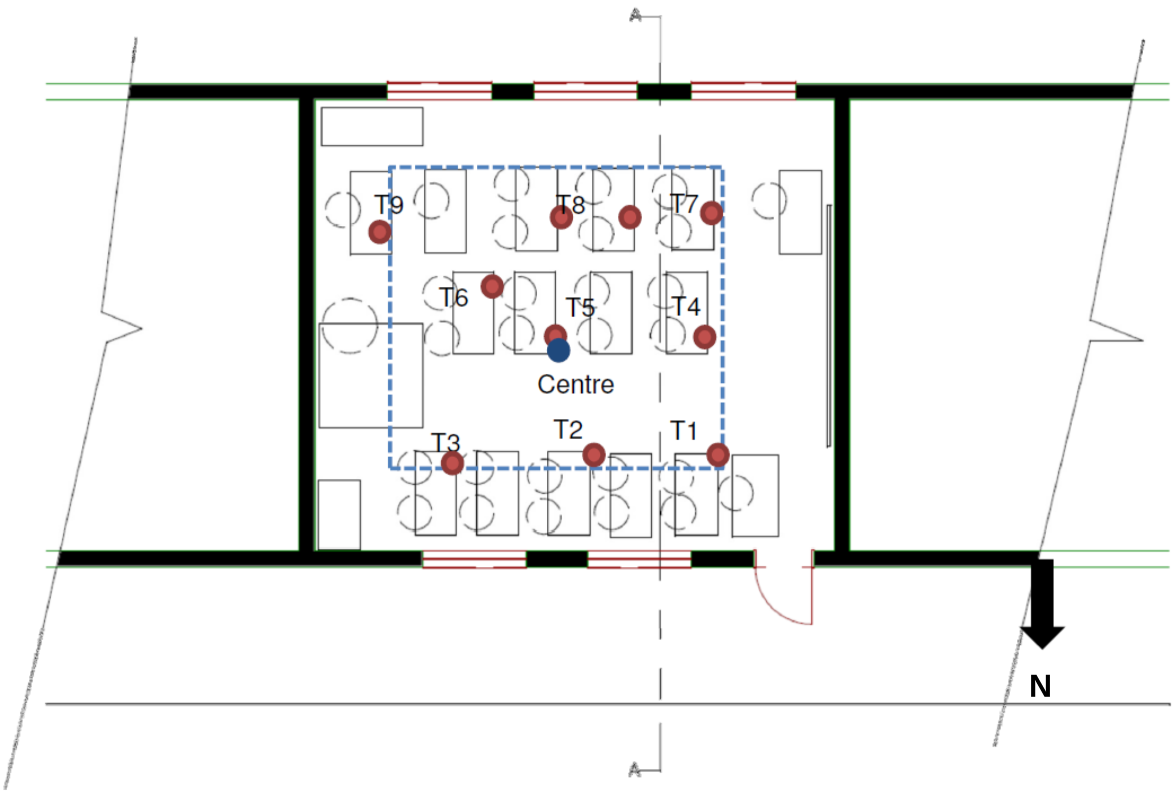


Figure 28 The grade 6 classroom

Table 30 Grade 6 classroom temperature averages

Average temperature at desks	09/09/2013	10/09/2013	11/09/2013	12/09/2013	13/09/2013	Average
Min. ave. temp	17.9	19.9	20.01	21.62	20.98	**20.082**
Max. ave. temp	27.4	28.2	28.48	27.27	28.46	**27.962**

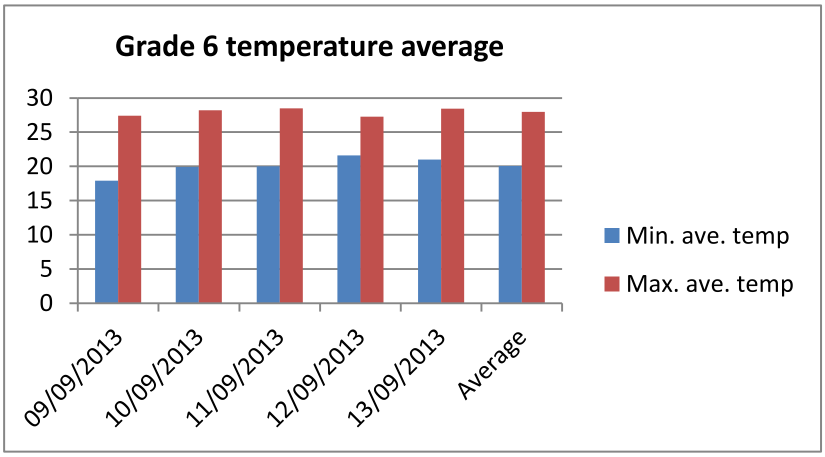


Table 30 shows the average minimum and maximum temperatures for 9 September 2013 to 13 September 2013 ranged from 20.1°C to 27.9°C between 08:00 and 14:00.

5.1.3.1 Discussion

The average internal air temperature experienced by the grade 6 learners ranges from a minimum of 20.1°C to a maximum of 27.9°C. The average minimum temperatures are within the range recommended by the thermal comfort standards (i.e 22°C to 27°C) and maximum temperatures are slightly above. The average maximum temperatures occur in the afternoon before school ends and the average minimum temperature occur in the mornings. The air temperature in the classroom increases gradually throughout the day. However, minimum temperatures fall below the recommendations and the maximum temperature is above the recommendations. High temperatures occur at the front of class. No perception survey was taken for this class owing to learners' unavailability.

5.1.4 Grade 7: 09/09/2013 - 13/09/2013

Actual temperature data for grade 7 was collected for a week from 9 September to 13 September 2013 from 08:00 to 14:00. Refer to addenda B for actual desk air temperature measurements.

Figure 29 below shows the location of air temperature data loggers in the grade 7 classroom for the measurement of the actual air temperature

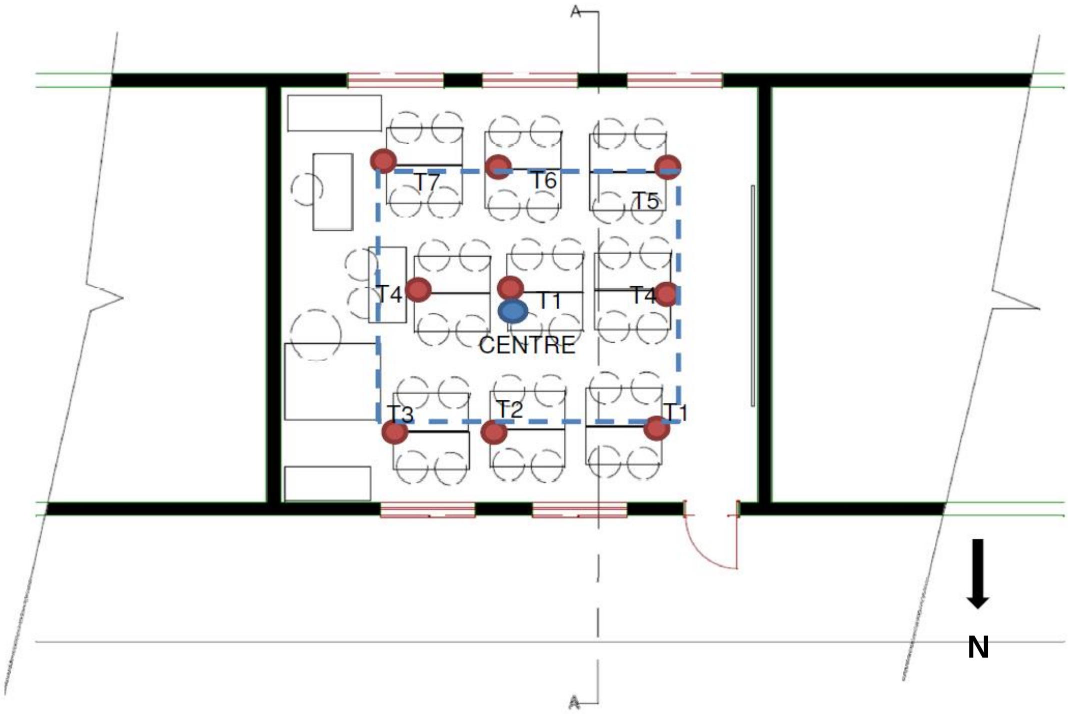


Figure 29 The grade 7 classroom

Table 31 The grade 7 classroom actual temperature averages (09/09/2013 -13/10/2013)

Average temperature at desks	09/09/2013	10/09/2013	11/09/2013	12/09/2013	13/09/2013	Average
Min. ave. temp	17.7	19.88	19.3	20.9	20.7	19.696
Ave.max.temp	28.3	27.76	28.9	27.2	29.2	28.272

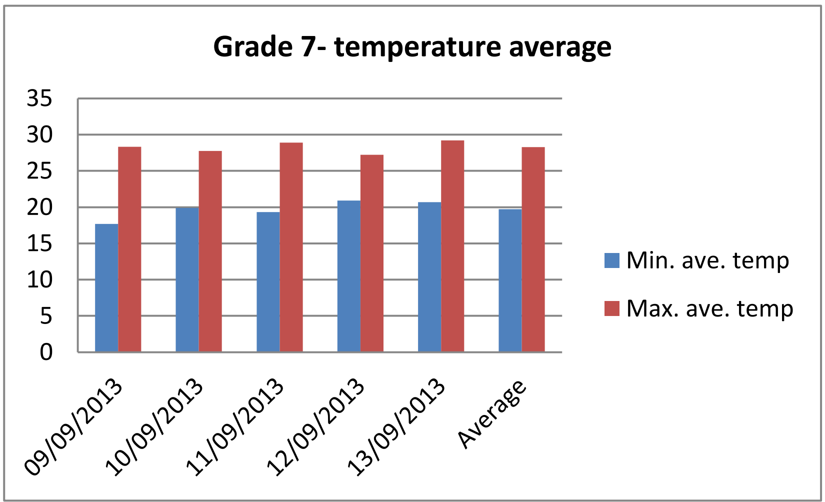


Table 31 shows that average minimum and maximum temperatures for 9 September 2013 to 13 September 2013 ranged from 19.7°C to 28.3°C between 08:00 and 14:00.

5.1.4.1 Discussion

The average internal air temperature experienced by the grade 7 learners ranges from a minimum of 19.7°C to a maximum of 28.3°C . The minimum temperatures are below the recommended range by the thermal comfort standards; however, the average maximum temperature is in most cases within the recommended range and occassionally ±3°C greater than the recommended temperature, i.e 22°C to 27°C . These average maximum temperatures occur in the afternoon before school ends. The minimum temperature occurs in the mornings. The air temperature in the classroom increases gradually throughout the day.

5.1.4.2 Learner thermal comfort perception

To measure the learners' perception of thermal comfort, the grade 7 learners were asked about their satisfaction levels regarding the temperature around their desks. The learners were asked to select the satisfaction level that best described their level of satisfaction. See table 32 below.

Are you satisfied with the surrounding TEMPERATURE at your desk?

Table 32 Satisfaction scale

Satisfaction level	Scale	Satisfied
Very satisfied	2	
Satisfied	1	
Ok	0	
Not satisfied but accepted	-1	
Not satisfied, not acceptable	-2	Unsatisfied

The classroom was divided into three sections for the location of learners to assess close proximity to walls / windows. In this classroom, Sections A and C were close to windows; section B was in the middle. See figures 30 and 31 below.

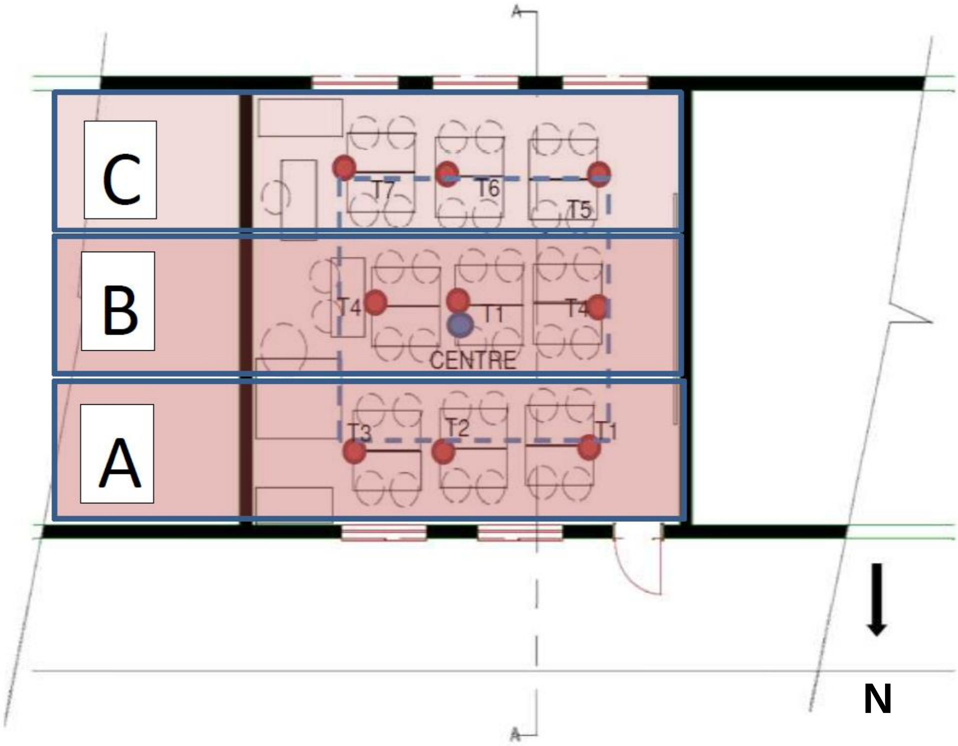


Figure 30 The 3 sections of the classroom

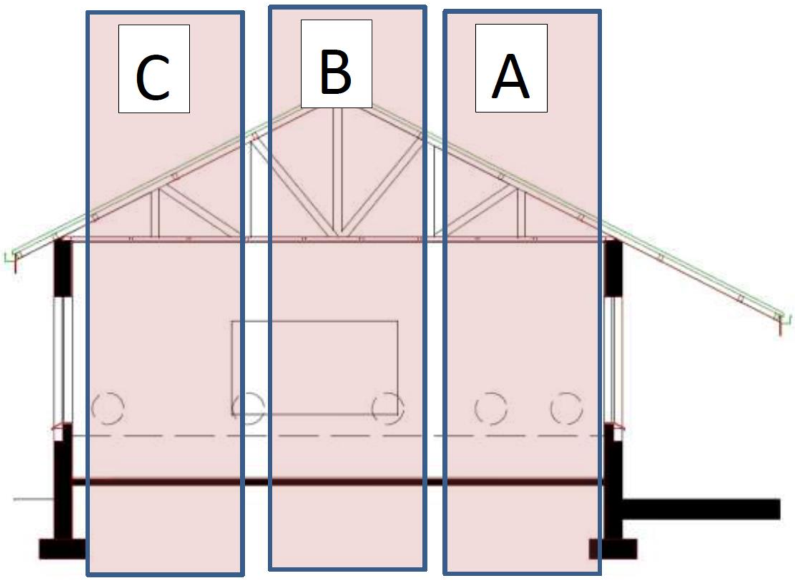


Figure 31 Sections of classroom

TABLE 33 THERMAL SATISFACTION RESPONSE (16/09/2013)

Section A		**Section B**		**Section C**	
Satisfaction scale	***No. of Students***	***Satisfaction scale***	***No. of Students***	***Satisfaction scale***	***No. of Students***
2	4	2	3	2	3
1	3	1	2	1	-
0	1	0	1	0	2
-1	1	-1	2	-1	1
-2	1	-2	3	-2	4
	10		**11**		**10**

Table 33 shows the responses of the 31 learners that participated in the survey recorded on the afternoon of ***16 September 2013 (2 days after the actual temperature data was recorded).***

Section A: 4 learners were very satisfied with the temperature at their desks, 3 learners were satisfied, 1 learner was OK and 1 learner was not satisfied but accepted the temperature and 1 learner was not satisfied and did not accept the temperature around his / her desk.

Section B: 3 learners were very satisfied with the temperature at their desks, 2 learners were satisfied, 1 learner was OK and 2 learners were not satisfied but accepted the temperature and 3 learners were not satisfied and did not accept the temperature around their desks.

Section C: 3 learners were very satisfied with the temperature at their desks, 2 learners were OK and 1 learner was not satisfied but accepted the temperature and 4 learners were not satisfied and did not accept the temperature around their desks.

Table 34 Learner thermal comfort satisfaction level

Satisfaction level	Learners
-2	8
-1	4
0	4
1	5
2	10
(blank)	9
Grand Total	**40**

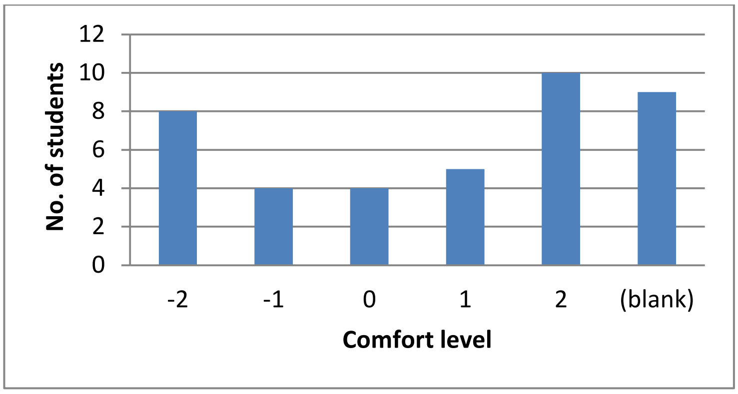


Table 34 shows that on 16/09/2013, 31 grade 7 learners that completed the thermal comfort satisfaction survey; 15 learners were satisfied with the temperature at their desks, 4 learners were OK with the temperature and 4 learners was not satisfied but accepted the temperature and 8 learners were not satisfied and did not accept the temperature around their desks.

It is assumed that 41% (13 out of 31) learners that voted -1, 0 and 1 are satisfied with the thermal conditions.

The learners near open windows and the door (Section A) are more satisfied with the thermal conditions; whereas, learners located in the middle of the room and next to closed windows (Sections B & C) are only partly satisfied.

5.1.5 **Discussion**

The air temperature data collected at the desks of learners in Bothlabatsatsi Primary School shows that the temperatures fell largely within the thermal comfort standards recommendations. The maximum air temperature deviated slightly from the recommended by ± 1.5 - 3°C.

The varying temperatures in the classrooms may be affected by the location of classrooms on site. For example, the grade 3 classroom has the highest air temperature because it is located on the northern side of the site. Whereas, the classrooms used by grades 5, 6 and 7 are on the south of the site and have lower temperature ranges.

The actual daily outside temperatures were not taken for this study. The monthly themperature average for the City of Tshwane (Pretoria) (see table 15) was used to check the impact on the internal temperatures of the external temperature. The average minimum temperature for the month of September in CoT is ±12°C and the maximum temperature is ±26°C.

The average minimum internal temperature for the classrooms ranged from 19°C to 21°C and the average maximum temperature ranged from 27°C to 31.8°C.

The comparison between the daily minimum temperature in the classroom and the external monthly minimum temperature average shows that the internal classroom temperature was higher by 7°C - 9°C. The daily maximum temperature in the classrooms compared to the external monthly temperature shows that it was higher by 1°C - 5.8°C.

Only two classes completed the learner survey, that is grades 3 and 7.The majority of the grade 3 learners stated that they were OK when asked if they agreed or disagree that the classroom was hot or cold. Almost half of the grade 7 learners expressed satisfaction with their thermal conditions; however, the other half expressed dissatisfaction.

The actual temperature taken on the day of the survey in the grade 3 classroom was both slighty higher and slighty lower than that recommended by the thermal comfort standards, but most of the learners expressed satisfaction nevertheless.

The learners' uniform insulation was in most cases within the 0.5cl range while some were slightly above. The clothing insulation did not affect the learners' thermal sensation.

The learners' activity level was low resulting in a low metabolic rate and low heat output.

5.2 Case study B: Meetse-a-Bophelo primary school

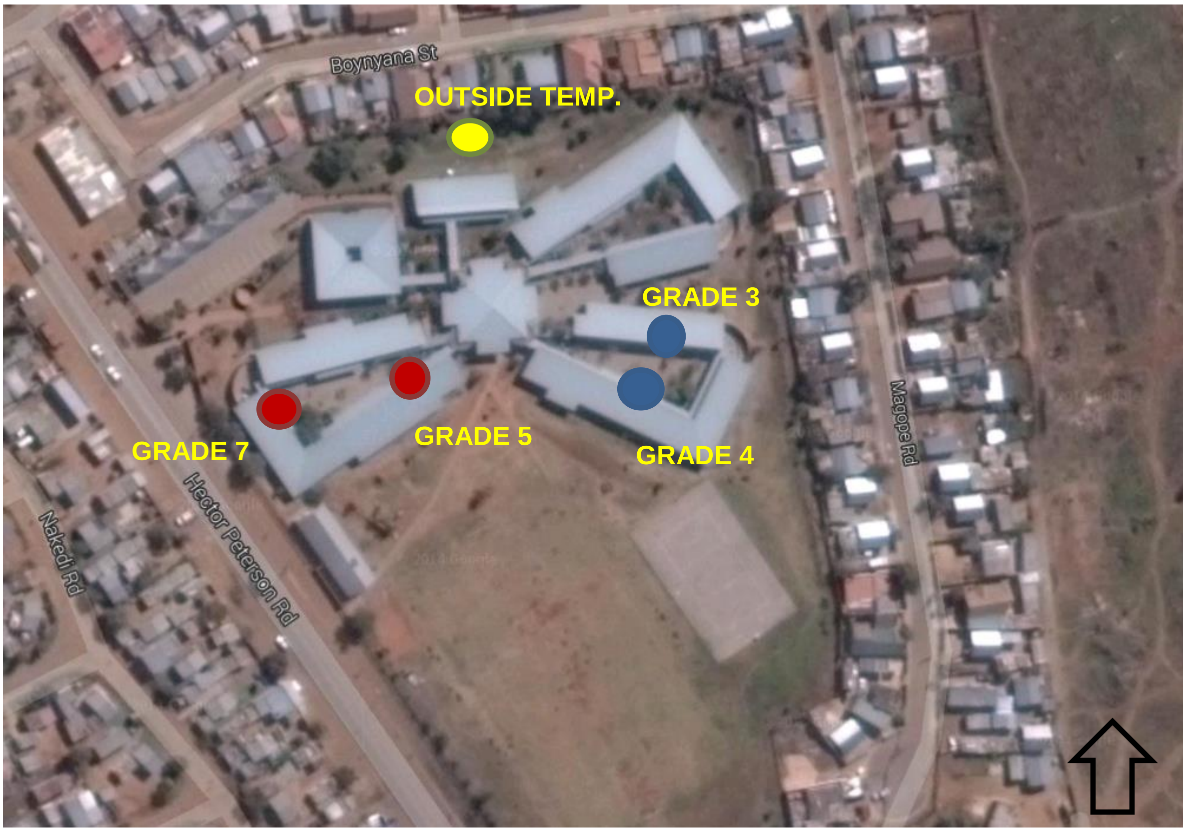


Figure 32 Meetse-a-Bophelo primary school: location of classrooms for study, arial photograph (courtesy of Google earth 2013)

Meetse-a-Bophelo primary school's 2013 statistics show that there were a total of 1 733 learners attending the school (See addenda B). This classifies Meetse-a-Bophelo primary school as a mega primary school, where there can be more than three classes per grade. Meetse-a-Bophelo primary school has up to seven classes per grade. The selected classrooms for this study are the grade 3D classroom with an occupancy of 57 learners, grade 4D with an occupancy of 63 learners, grade 5C with an occupancy of 52 learners, and grade 7A with an occupancy of 60 learners. In total 232 learners were expected to participate in this study.

Meetse-a-Bophelo primary school faces north. The grade 3D classroom is located on the east-south-east of the site and grade 4D is located on the south east of the site, grade 5A is located on the south west and grade 7A is located on the west side of the school site. The classrooms are in linear blocks, surrounded by open courtyards allowing for sufficient ventilation.

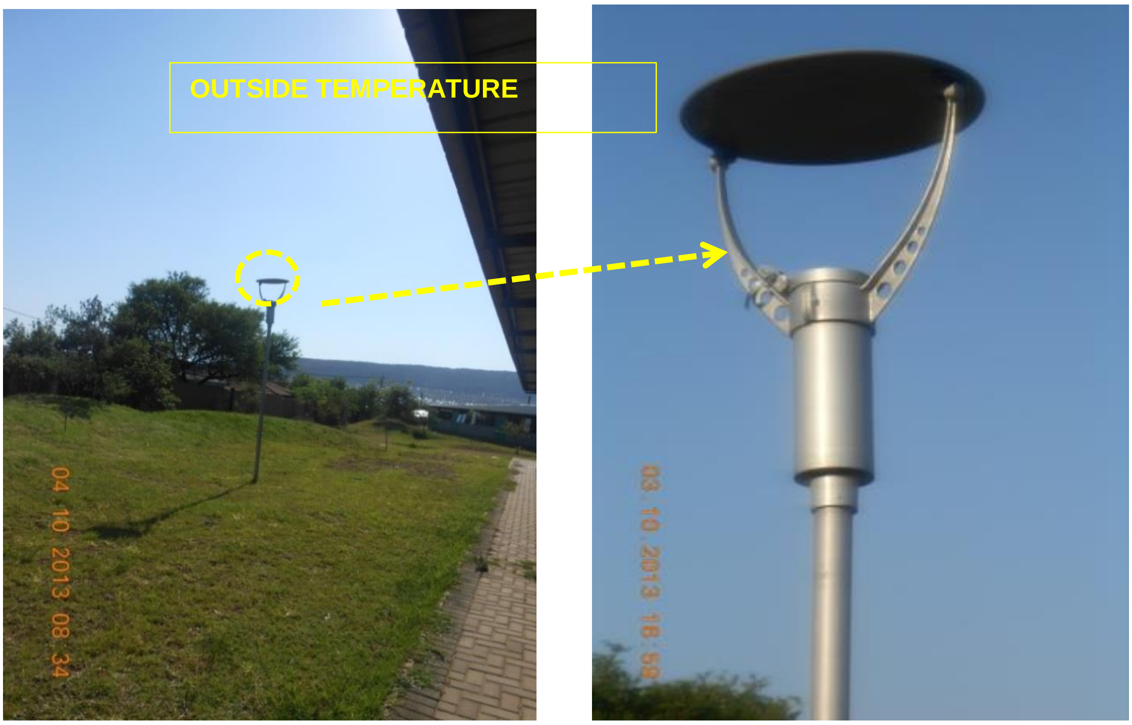


Figure 33 Meetse-a-Bophelo: location of outside logger

Figure 33 shows the location of the temperature data logger secured on the lamp outside.

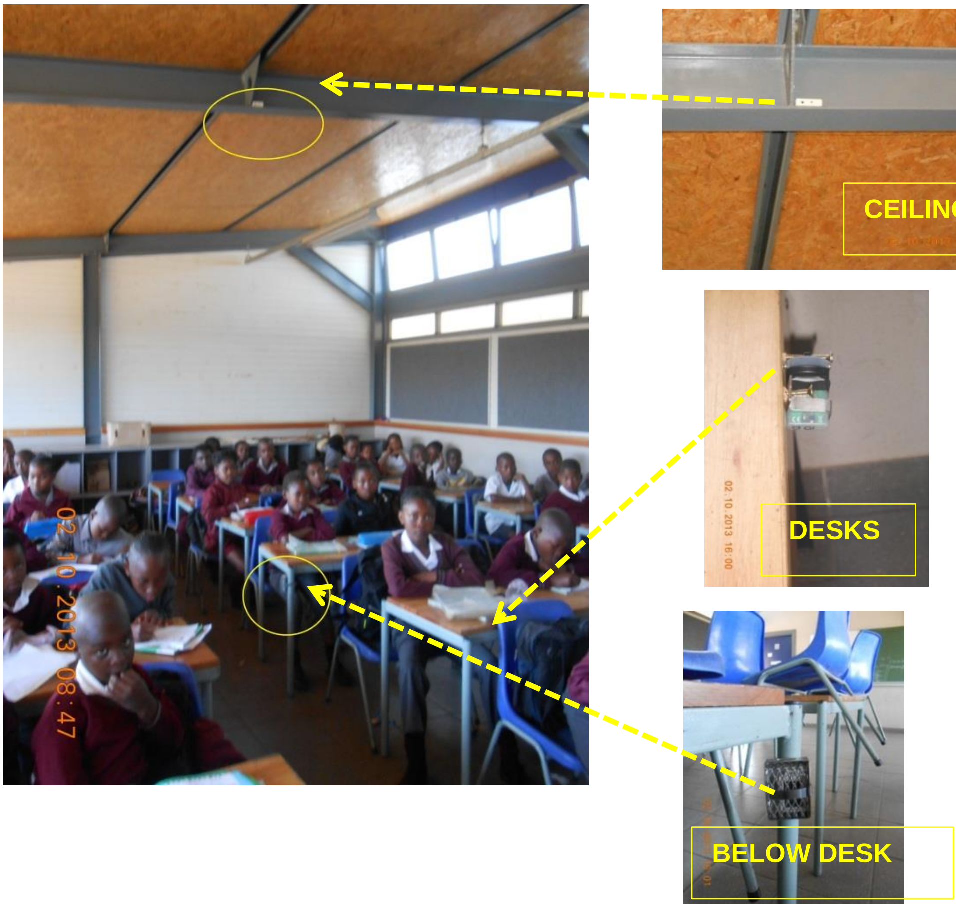


Figure 34 Meetse-a-Bophelo: location of data loggers inside classrooms

Figure 34 shows the location of temperature data loggers in the classroom.

5.2.1 **Grade 3D: 02/10/2013 - 08/10/2013**

The actual temperature data for grade 3D was collected for a week from 2 October to 8 October 2013 between 08:00 and 14:00. Data was collected outside, at the ceiling, at the centre of class and at learners' desks. The data loggers were left in their positions for the duration of the study; hence, the study measured whole day temperatures (daytime and night-time, with and without occupancy, including a weekend - 5 October 2013 and 6 October 2013).

Refer to addenda B for actual desk air temperature measurements.

(N/R indicates no reading recorded)

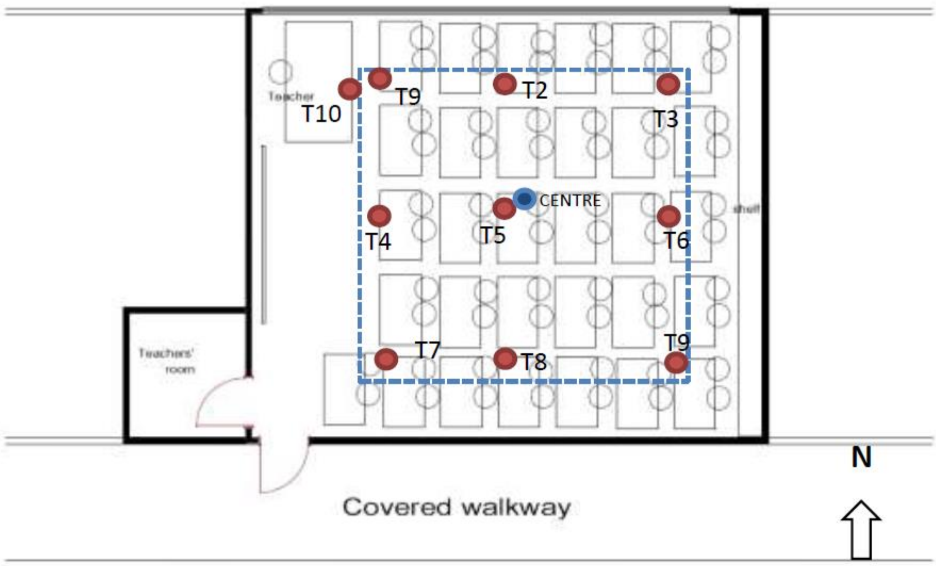


Figure 35 Location of loggers

Figure 35 shows the location of the loggers.

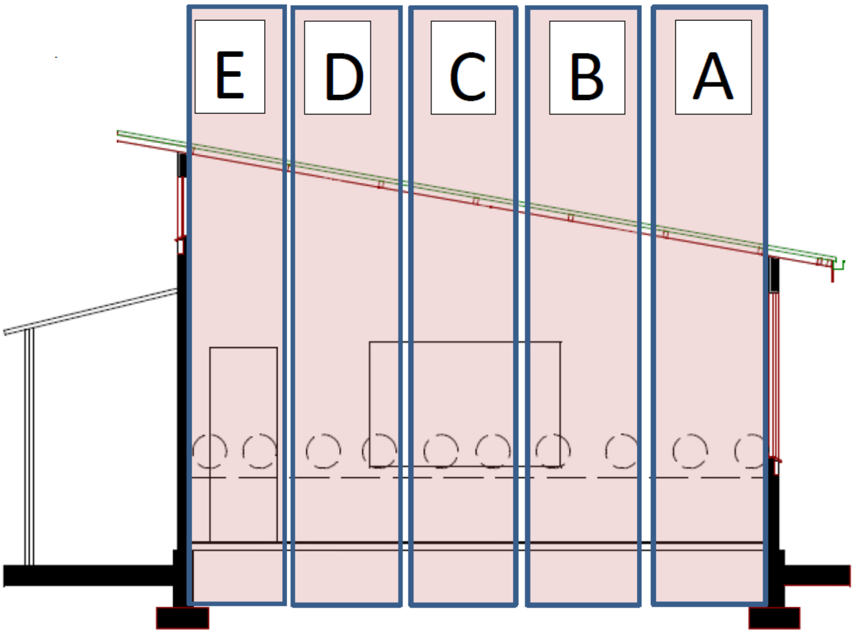


Figure 36 Sections of classroom

Figure 36 shows where data was collected in the different sections of a classroom.

5.2.1.1 Outside temperature

Table 35 Minimum & maximum outside temperature

Outside temperature 08:00-14:00	Min temp.	Max temp.
03/10/2013	25.8	34.3
04/10/2013	22.7	32.1
05/10/2013	25.1	36
06/10/2013	25.6	34.6
07/10/2013	18.8	30
08/10/2013	20.8	29.6
Average	**23.1**	**32.76**

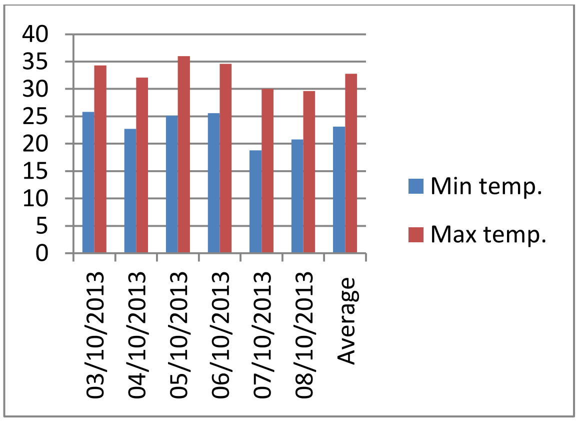


Table 35 show temperatures taken outside of the classrooms from 3 October 2013 to 8 October 2013 and between 08:00 and 14:00. The minimum temperature outside (in the morning at 08:00) was 18.8°C and was recorded on 7 October 2013. The maximum temperature outside (in the afternoon at 14:00) was 36°C and was recorded on 5 October 2013. Temperature readings for 2 October 2013 were not recorded.The averages for outside minimum and maximum temperatures from 3 October 2013 to 8 October 2013 ranged from 23.1°C to 32.8°C between 08:00 and 14:00.

5.2.1.2 Ceiling temperature

Table 36 Minimum & maximum ceiling classroom temperatures

Ceiling temperature 08:00-14:00	Min temp.	Max temp.
02/10/2013	16	36.1
03/10/2013	18.7	35.7
04/10/2013	18.3	33.6
05/10/2013	20.2	36.1
06/10/2013	21.3	37
07/10/2013	19.8	31.9
08/10/2013	18.3	29.9
Average	**19.43**	**34.03**

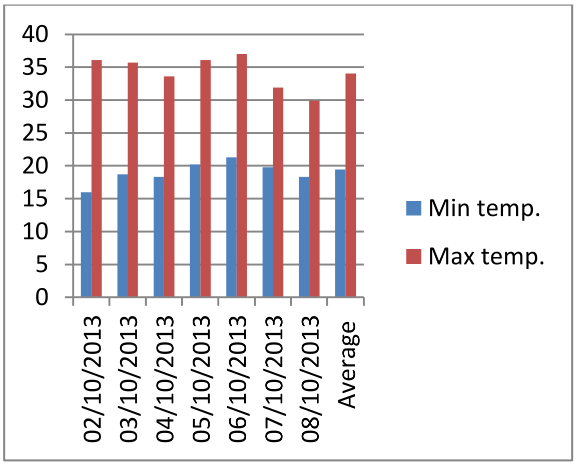


Table 36 shows temperatures taken inside the classroom on the ceiling from 3 October 2013 to 8 October 2013 and between 08:00 and 14:00. The minimum ceiling temperature (in the morning at 08:00) was 16°C and was recorded on 2 October 2013. The maximum ceiling temperature (in the afternoon at 14:00) was 36.1°C and was recorded on 2 October 2013 and 5 October 2013. The averages for minimum and maximum temperatures for the ceiling from 3 October 2013 to 8 October 2013 ranged from 19.4 ° C to 34°C between 08:00 and 14:00

Table 37 Minimum & maximum central classroom temperatures

Central temperature 08:00-14:00	Min temp.	Max temp.
02/10/2013	N/R	N/R
03/10/2013	19.8	31.1
04/10/2013	19.1	29.9
05/10/2013	20.7	29.6
06/10/2013	21.5	30.7
07/10/2013	20.3	29.6
08/10/2013	19.2	28.9
Average	**20.1**	**29.9**

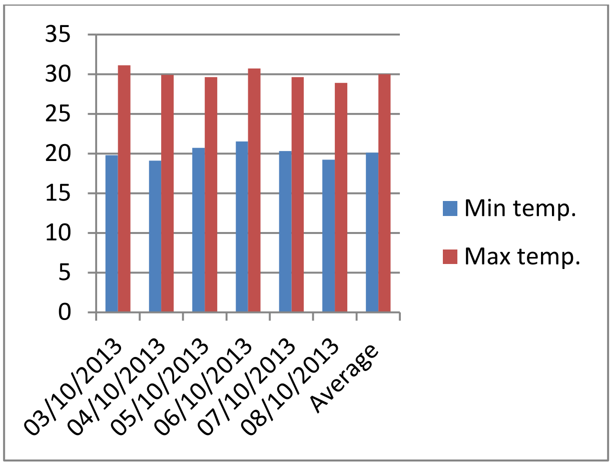


Table 37 shows temperatures taken inside the classroom at the centre from 3 October 2013 to 8 October 2013 and between 08:00 and 14:00. The minimum temperature (in the morning at 08:00) at the centre was 19.1°C and was recorded on 4 October 2013. The maximum temperature (in the afternoon at 14:00) at the centre was 31.1°C and was recorded on 3 October 2013. The average minimum and maximum temperatures for the centre of the classroom from 3 October 2013 to 8 October 2013 ranged from 20.1 ° C to 29.9°C between 08:00 and 14:00.

Table 38 Average outside/ceiling / central maximum classroom temperatures

Date	Outside Max temp.	Max. Ceiling	Max. Central
02/10/2013	N/R	36.1	0
03/10/2013	34.3	35.7	31.1
04/10/2013	32.1	33.6	29.9
05/10/2013	36	36.1	29.6
06/10/2013	34.6	37	30.7
07/10/2013	30	31.9	29.6
08/10/2013	29.6	29.9	28.9
Average	**32.76**	**34.33**	**29.96**

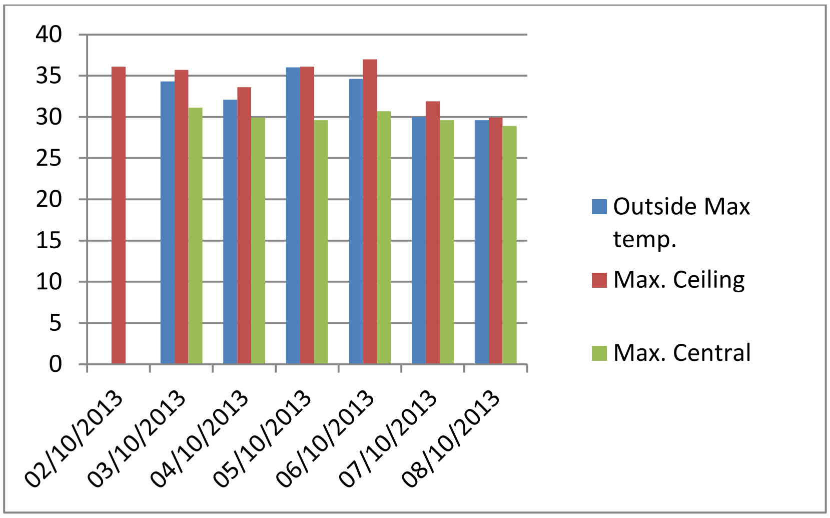


Table 38 shows that the outside maximum temperature was 34.6° C, the maximum ceiling temperature is 36.1° C and the central maximum temperature was 31.1° C. The average maximum temperatures for the outside, the ceiling and the centre of the classroom from 3 October 2013 to 8 October 2013 ranged from 29.9°C to 34° C between 08:00 and 14:00. (Outside 32.8°C, ceiling 34.3°C and central 29.9°C.)

Table 39 Average outside / ceiling / central minimum classroom temperatures

Date	Outside min. temp.	Ceiling min.	Central min.
02/10/2013	N/R	16	0
03/10/2013	25.8	18.7	19.8
04/10/2013	22.7	18.3	19.1
05/10/2013	25.1	20.2	20.7
06/10/2013	25.6	21.3	21.5
07/10/2013	18.8	19.8	20.3
08/10/2013	20.8	18.3	19.2
Average	**23.13**	**18.94**	**20.1**

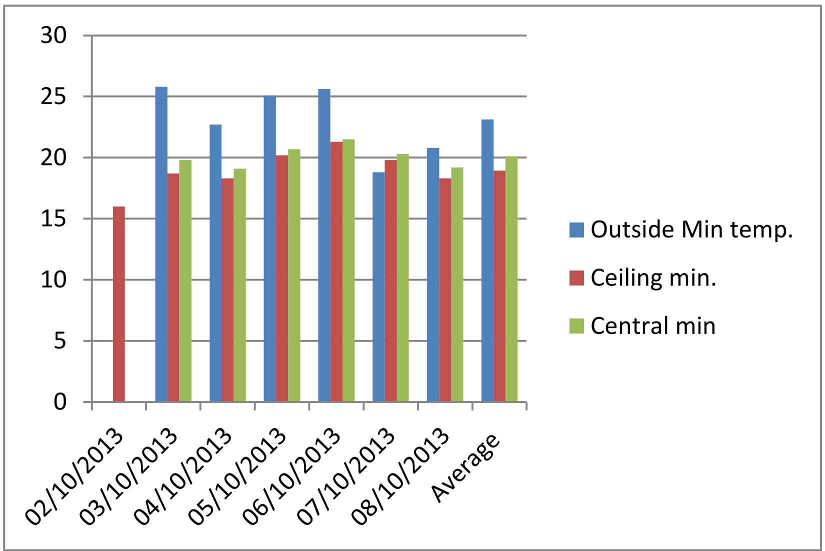


Table 39 shows that the outside minimum temperature was 18.8°C, the minimum ceiling temperature was 16°C and the central minimum temperature was 19.1°C. The average minimum temperatures for the outside, the ceiling and the centre of the classroom from 3 October 2013 to 8 October 2013 ranged from 18.9°C to 23.1°C between 08:00 and 14:00 (Outside 23.1°C, ceiling 18.9°C and central 20.1°C).

5.2.1.3 Discussion

The average maximum internal temperature was at the ceiling (34.3°C) and was greater than the average maximum outside temperature (32.8°C) by about 1.5°C and greater than the central temperature by 5°C. This means that the ceiling was trapping heat coming in from the outside through the roof resulting in the outside temperature being reduced to 29.9°C internally.

The minimum temperature outside (23.1°C) was higher than the ceiling temperature (18.9°CC) by 4.8°C and higher than the central temperature (20.1°C) by 3°C.

The outside temperature gradually heats up the internal spaces through the day. The internal space is also warmed up by heat generated by the learners. The high morning temperatures conveys that the heat trapped by the ceiling was transferred to the internal air via convection and as the windows were closed after school the hot air remained trapped inside.

Thermal comfort standards recommend that the ceiling radiant asymmetry be less than 5°C of the air temperature to avoid thermal discomfort. The ceiling temperature in the classroom was lower than the internal temperature by less than 5°C therefore the learners should not experience thermal discomfort from heat coming from ceiling.

Table 40 Average temperatures at desks (1-10)

Average temperature at desks	T 1	T 2	T3	T 4	T 5	T 6	T 7	T 8	T 9	T 10	Average
Ave.min.temp	19.7	19.9	19.7	20.1	20.5	20.5	19.3	19.37	19.43	19.86	**19.836**
Ave.max.temp	29.8	30.3	30.2	30.3	30.6	30.6	29.7	30.3	29.4	31.03	**30.223**

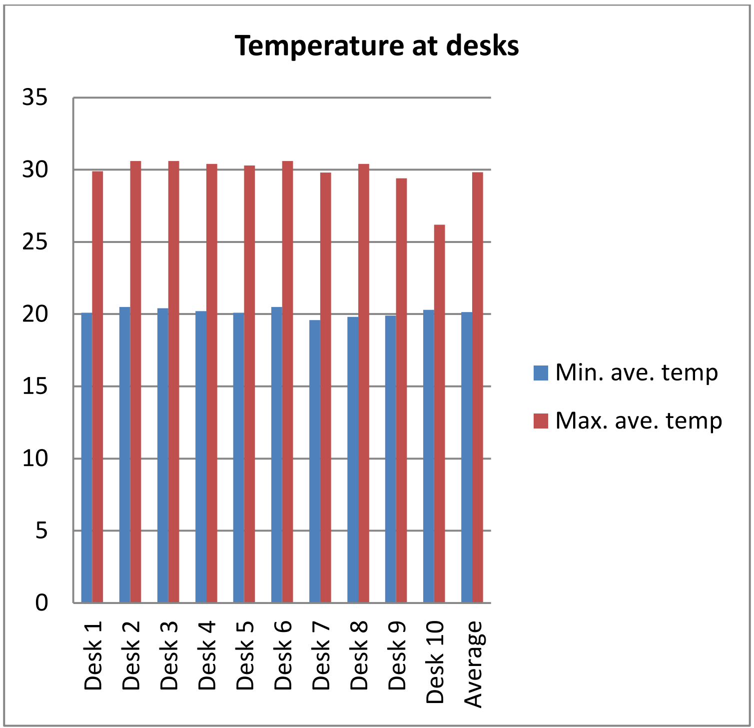


Table 40 shows that the average temperatures for the desks from 3 October 2013 to 8 October 2013 ranged from 19.8 ° C to 30.2° C between 08:00 and 14:00.

5.2.1.4 Discussion

The maximum temperatures recorded at all desks occurred on 3 October 2013 and 6 October 2013 (above 30°C). This was about 3°C greater than the temperature recommended by the thermal comfort standard. Outside temperatures were recorded to be their highest on these dates (slightly above 34°C). The minimum temperature occurred on 2 October 2013. The temperatures at the desks were slightly below and above the thermal comfort standard recommendations by ± 5°C.

5.2.1.5 Grade 3D learners' perception of the thermal comfort -11/10/2013

To measure the learners' perception of the thermal comfort, the grade 3 learners were asked to respond to two statements, that is, MY CLASSROOM IS HOT and MY CLASSROOM IS COLD through selecting one of five faces that describe agreement or disagreement with the statement. The five faces represent five scales that represent satisfaction. See table 22.

The location of learners in this class was not observed.

(N/R indicates no reading recorded)

Table 41 Learner thermal comfort sensation of classroom warmth

Comfort level	Student
-2	4
0	9
1	7
2	19
(blank)	1
Grand Total	**40**

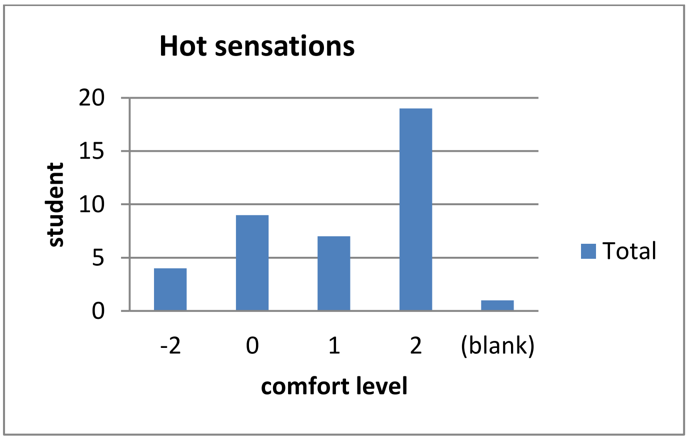


Table 41 shows the learners' thermal comfort sensations towards the warmth of the classroom. Out of the 40 grade 3 learners that participated in the research, 19 learners strongly agreed that they were hot, 7 learners agreed that they were hot, 9 learners were OK, and 4 learners strongly disagreed with the statement. Of the 39 learners that participated in the research, 26 felt that they were hot.

It is assumed that 41% (16 out of 39) learners that voted 0 and 1 are satisfied with the thermal conditions.

Table 42 Learner thermal comfort sensation of classroom coolness

Comfort level	Count
-2	6
-1	3
0	8
1	5
2	16
(blank)	2
Grand Total	**40**

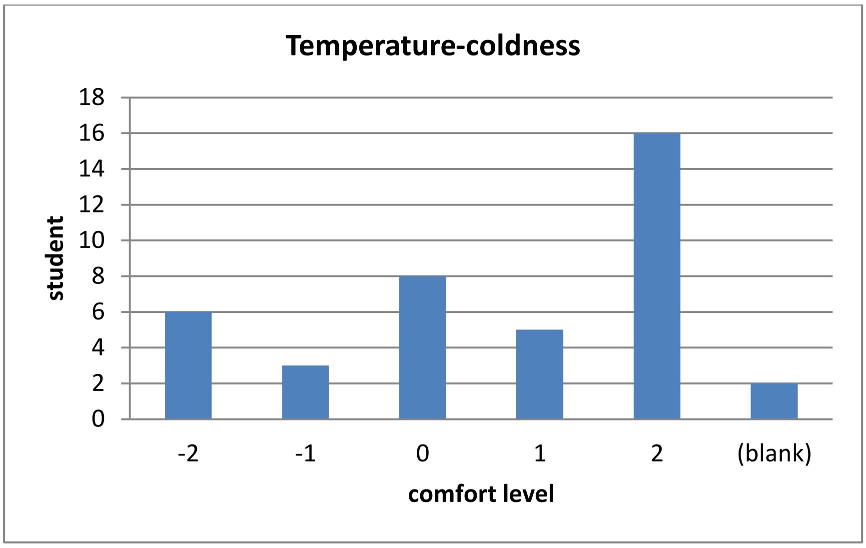


Table 42 shows the learners' thermal comfort sensations towards the coldness of the classroom. Out of the 40 grade 3 learners that participated in the research, 16 learners strongly agreed that they were cold, 5 learners agreed that they were cold, 8 learners were OK, and 9 learners disagreed with the statement. Of the 39 learners that participated in the research, 19 felt that they were cold.

It is assumed that 42% (16 out of 38) learners that voted -1,0 and 1 are satisfied with the thermal conditions.

Table 43 The correlation of clothing insulation and thermal sensation (warmth)

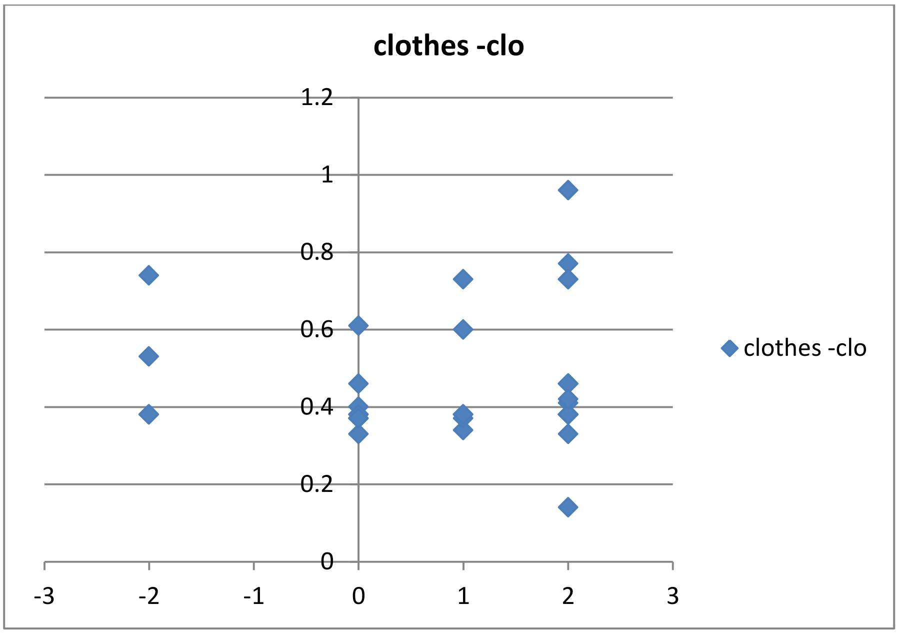
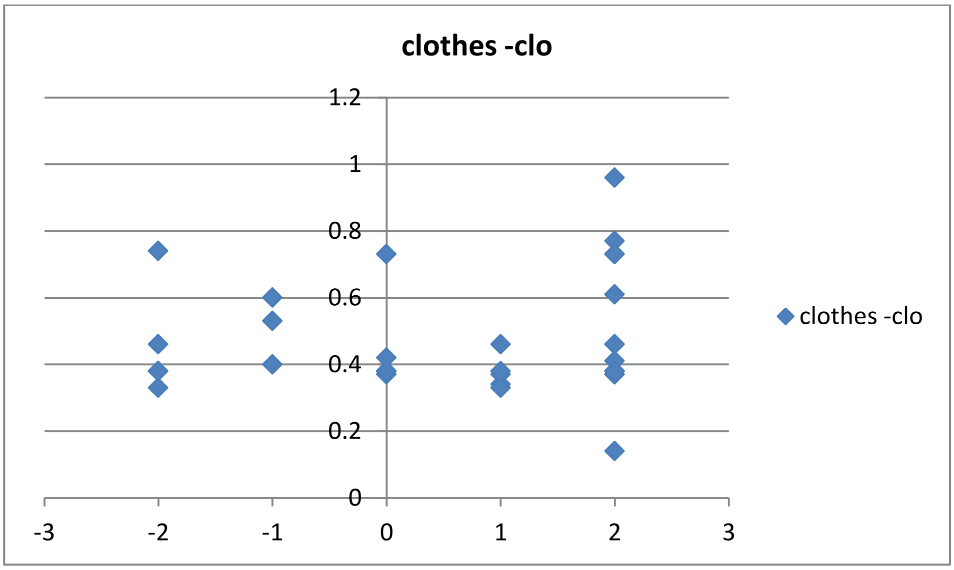


Table 44 The correlation of clothing insulation and thermal sensation (coolness)



Tables 43 and 44 show that the linear correlation is near zero, meaning that no relationship exists between what the learners are wearing and their thermal sensations. Therefore, clothing insulation did not influence learners' thermal sensation.

5.2.2 Grade 4D: 02/10/2013 - 08/10/2013

The actual temperature data for grade 4D was collected for a week from 2 October to 8 October 2013 between 08:00 and 14:00. Data was collected outside, at the ceiling, at the centre of class and at learners' desks. The data loggers were left at their positions for the duration of the study; hence, the study measured whole day temperatures (daytime and night-time, with and without occupancy, including weekends – 5 October 2013 and 6 October 2013).

Refer to addenda B for actual desk air temperature measurements.

(N/R indicates no reading recorded)

Learners' perception of the thermal comfort of the grade 4D classroom was not gathered due to learner unavailability.

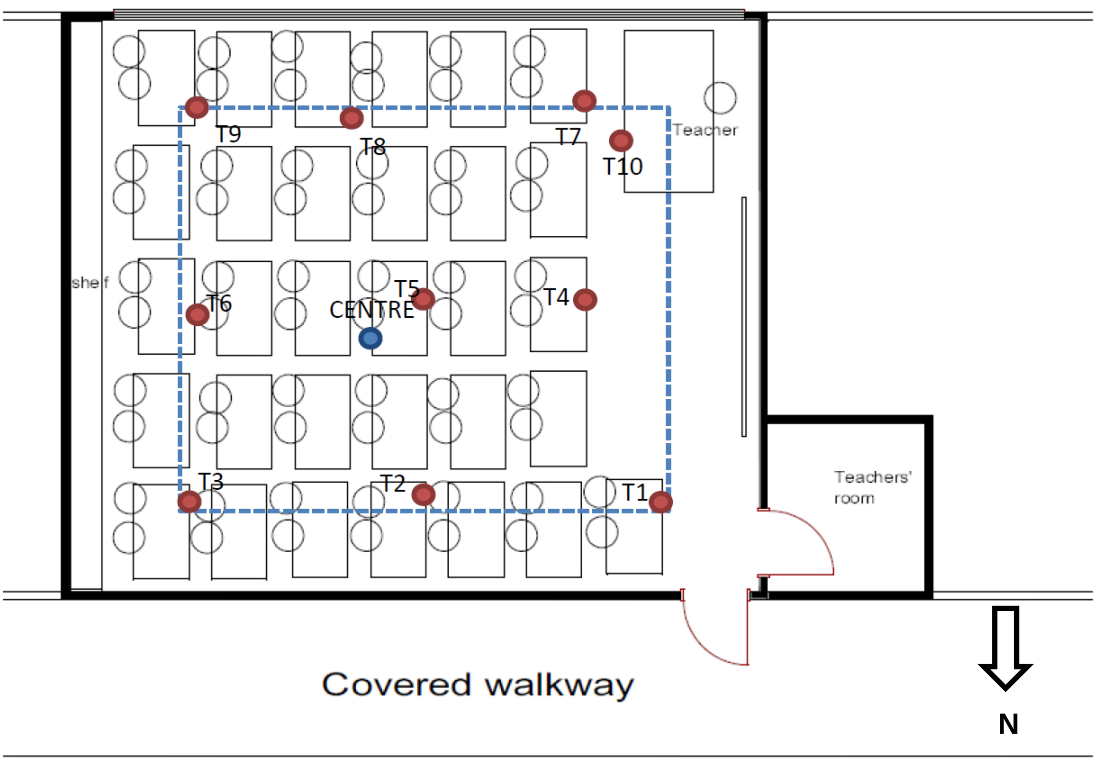


Figure 37 Position of loggers

5.2.2.1 Outside temperature

Table 45 Minimum & maximum outside temperatures

Outside temperature 08:00-14:00	Min temp.	Max temp.
03/10/2013	25.8	34.3
04/10/2013	22.7	32.1
05/10/2013	25.1	36
06/10/2013	25.6	34.6
07/10/2013	18.8	30
08/10/2013	20.8	29.6
Average	**23.1**	**32.76**

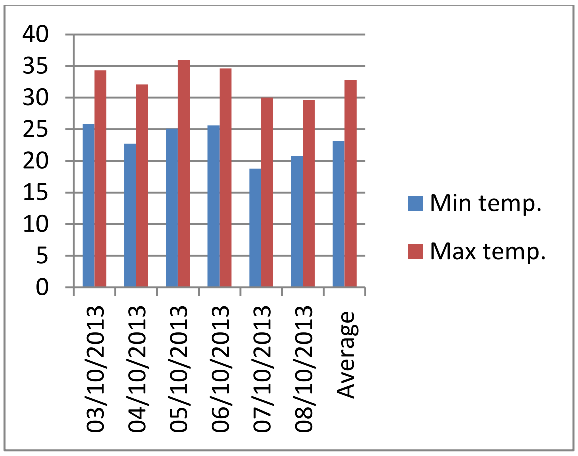


Table 45 shows temperatures taken in the outside classroom from 3 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) outside was 18.8°C and was recorded on 7 October 2013. The maximum temperature (taken in the afternoon - 14:00) outside was 36°C on 5 October 2013. Temperature readings for 2 October 2013 were not recorded.The average minimum and maximum temperatures for the outside temperature from 3 October 2013 to 8 October 2013 ranged from 23.1°C to 32.8°C between 08:00 and 14:00.

Table 46 Maximum outside/ceiling/central temperatures

Date	Outside Max temp.	Max. Ceiling	Max. Central
02/10/2013	N/R	31.9	N/R
03/10/2013	34.3	33.6	30.4
04/10/2013	32.1	32.8	30
05/10/2013	36	34	27.6
06/10/2013	34.6	35.7	29.7
07/10/2013	30	31.9	30.2
08/10/2013	29.6	28.7	28.9
Average	**32.76**	**32.65**	**29.46**

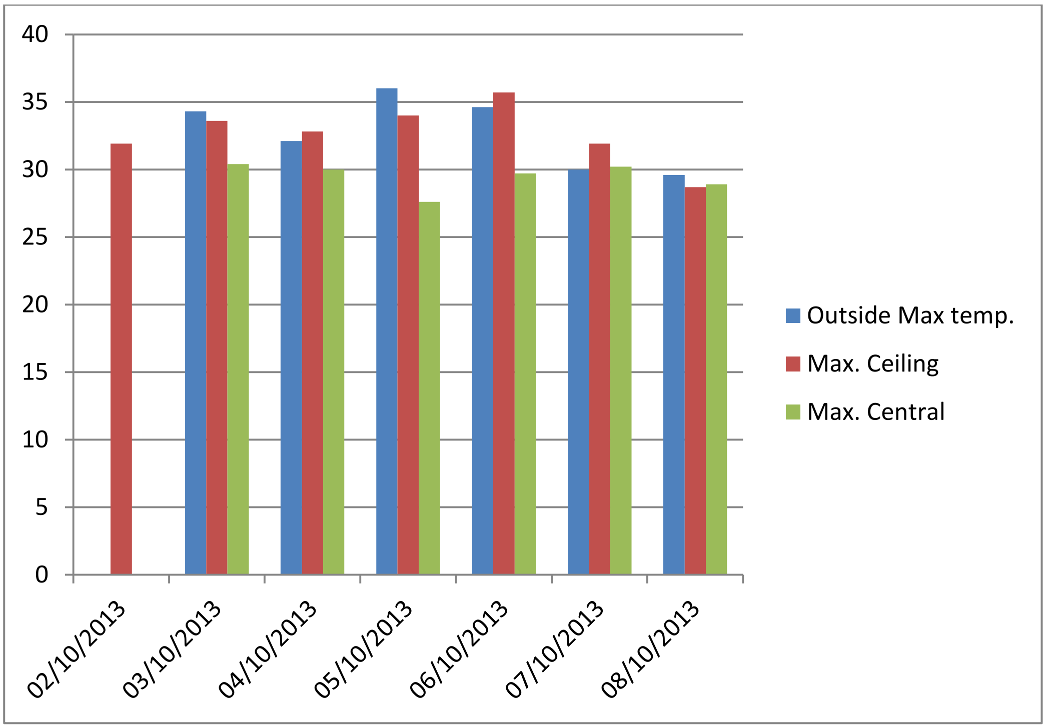


Table 46 shows the outside maximum temperature was 36.6° C, the maximum ceiling temperature was 35.7° C and the central maximum temperature was 30.4° C. The average maximum temperatures for the outside, the ceiling and the central temperature from 2 October 2013 to 8 October 2013 ranged from 29.5°C to 32.8°C between 08:00 and 14:00 (outside – 32.8°C; ceiling – 32.7°C; inside – 29.5°C).

Table 47 Minimum outside/ceiling/central temperatures

Date	Outside Min temp.	Ceiling min.	Central min
02/10/2013	N/R	14.5	N/R
03/10/2013	25.8	17.5	19.8
04/10/2013	22.7	17.9	19.1
05/10/2013	25.1	19	20.7
06/10/2013	25.6	20.2	21.5
07/10/2013	18.8	18.7	20.3
08/10/2013	20.8	17.5	19.2
Average	**23.13**	**17.9**	**20.1**

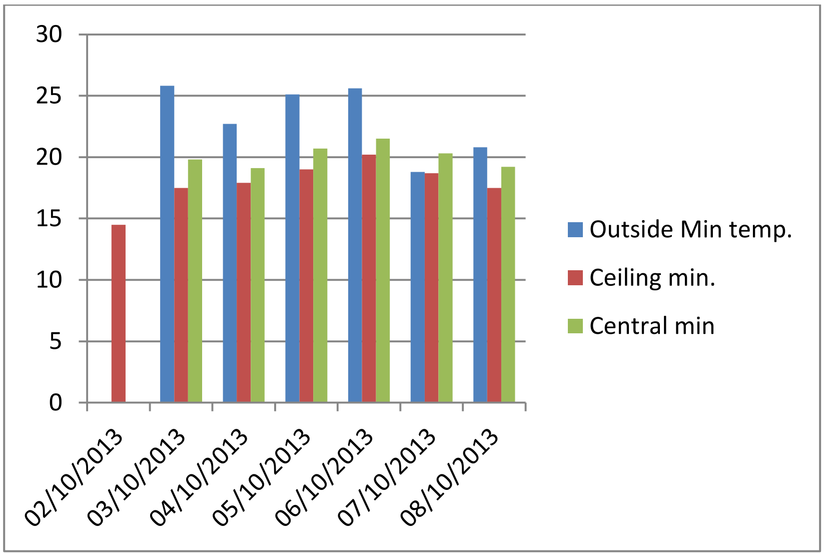


Table 47 shows that the outside minimum temperature was 18.8° C, the minimum ceiling temperature was 14.5° C and the central minimum temperature was 19.1° C. The average minimum temperatures for the outside, the ceiling and the central temperature from 2 October 2013 to 8 October 2013 ranged from 17.9°C to 23.1°C between 08:00 and 14:00. (Outside – 23.1°C; Ceiling – 17.9°C; Inside - 20.1°C)

5.2.2.2 Discussion

The maximum internal temperature was at the ceiling (32.7°C) and it was less than the outside temperature (32.8°C) by about 0.1°C and greater than the central temperature by 3.2°C. This means that the ceiling was trapping heat coming in from the outside through the roof resulting in the outside temperature being reduced to 29.5°C internally.

The minimum temperature outside (23.1°C) was higher than the ceiling temperature (17.9°C) by 5.2°C and higher than the central temperature (20°C) by 3°C.

The outside temperature gradually heats up the internal spaces through the day. The internal space is also warmed up by heat generated by the learners. The constant/high morning temperatures inside conveys that the heat trapped by the ceiling was transferred to the internal air via convection and because the windows were closed after school the hot air remained trapped inside.

Thermal comfort standards recommend that the ceiling radiant asymmetry be less than 5°C of the air temperature to avoid thermal discomfort. The ceiling temperature in the classroom was lower than the internal temperature by less than 5°C therefore the learners should not experience thermal discomfort from heat coming from ceiling.

Table 48 Average temperatures at desks (1-10)

Average temperature at desks	Desk 1	Desk 2	Desk 3	Desk 4	Desk 5	Desk 6	Desk 7	Desk 8	Desk 9	Desk 10	Average
Ave.min.temp	19.2	19.04	19.3	18.9	18.9	19.02	19.4	18.7	18.65	18.95	**19.006**
Ave.max.temp	29.9	29.81	30.8	29.6	29.9	29.9	28.01	29.6	28.2	30.5	**29.622**

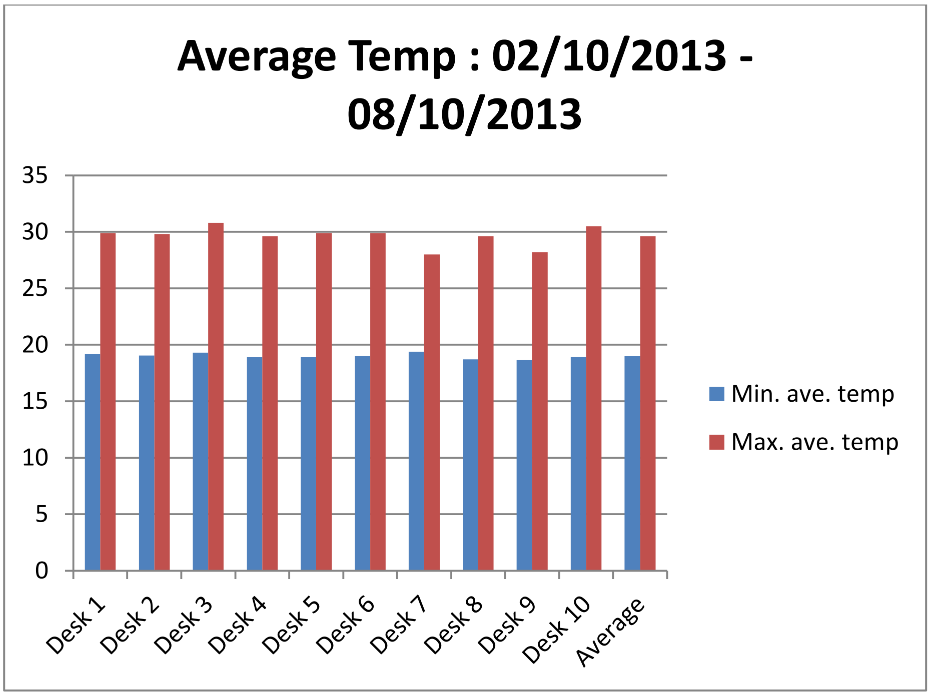


Table 48 shows that the average temperatures at the desks from 2 October 2013 to 8 October 2013 ranged from 19°C to 29.6°C between 08:00 and 14:00.The average maximum temperature at the desks was ± 29.7°C. The maximum temperatures are about ± 2.7° C greater than the temperature recommended by the thermal comfort standard and the minimum temperatures are ± 2.5° C lower than those recommended. The highest temperature recorded was at T10 and T3.

5.2.2.3 Discussion

The maximum and minimum temperatures recorded at all desks occurred on 2 October 2013 (around 15.6°C - 16.4°C) and 6 October 2013 (around 30.8 - 32.6°C) respectively. This is about 35°C to 5°C greater and lower than the temperature recommended by the thermal comfort standard. Outside temperatures were recorded at their highest (34.6°C) on 6 October 2013. The minimum temperature occurred on 2 October 2013. The temperatures at desks are slightly below and above the thermal comfort standard recommendations by ± 5°C.

5.2.3 **Grade 5A: 02/10/2013 - 08/10/2013**

The actual temperature data for grade 5C was collected for a week from 3 October to 8 October 2013 between 08:00 and 14:00. Data was collected outside, at the ceiling, at the centre of class and at learners' desks. The data loggers were left in their positions for the duration of the study; hence, the study measured whole day temperatures (daytime and night-time, with and without occupancy, including weekends - 5 October 2013 and 6 October 2013).

(N/R indicates no reading recorded)

Refer to addenda B for actual desk air temperature measurements.

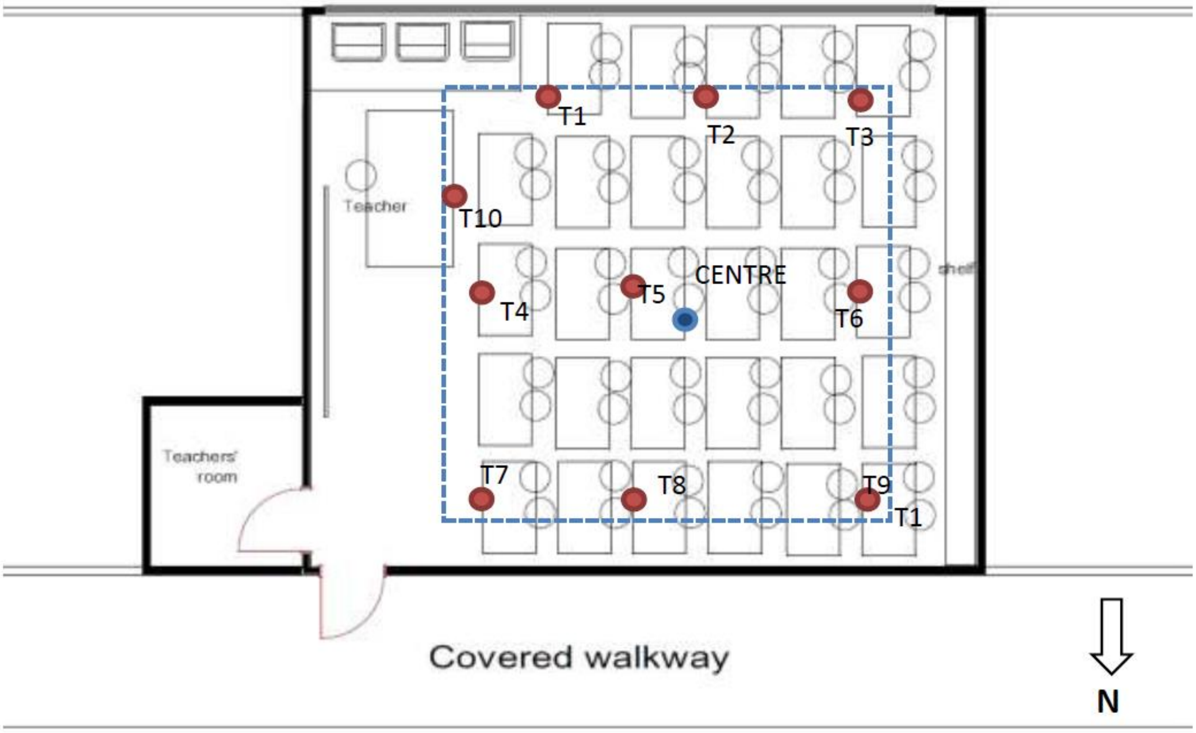


Figure 38 Location of loggers

5.2.3.1 Outside temperature

Table 49 Minimum & maximum outside temperatures

Outside temperature 08:00-14:00	Min temp.	Max temp.
03/10/2013	25.8	34.3
04/10/2013	22.7	32.1
05/10/2013	25.1	36
06/10/2013	25.6	34.6
07/10/2013	18.8	30
08/10/2013	20.8	29.6
Average	**23.1**	**32.76**

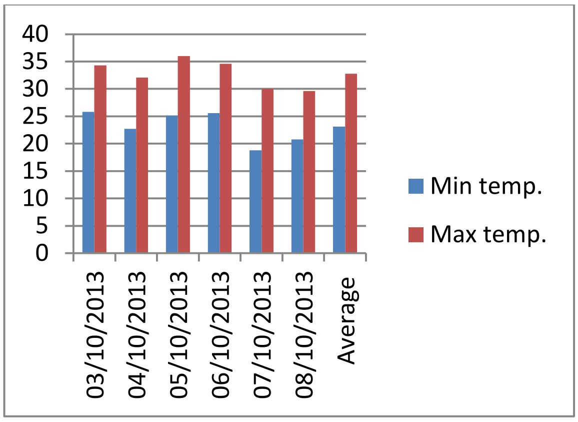


Table 49 show temperatures taken in the outside classroom from 3 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) outside was 18.8°C and was recorded on 7 October 2013. The maximum temperature (taken in the afternoon - 14:00) outside was 36°C and was recorded on 5 October 2013. Temperature readings for 2 October 2013 were not recorded.The average minimum and maximum temperatures for outside temperature from 3 October 2013 to 8 October 2013 ranged from 23.1°C to 32.8°C between 08:00 and 14:00.

Table 50 Maximum outside/ceiling/central temperatures

Date	Outside Max temp.	Max. Ceiling	Max. Central
02/10/2013	N/R	31.1	N/R
03/10/2013	34.3	31.5	30
04/10/2013	32.1	31.5	29
05/10/2013	36	31.9	28.1
06/10/2013	34.6	33.2	30.4
07/10/2013	30	31.9	30.4
08/10/2013	29.6	29.9	27.6
Average	**32.76**	**31.57**	**29.25**

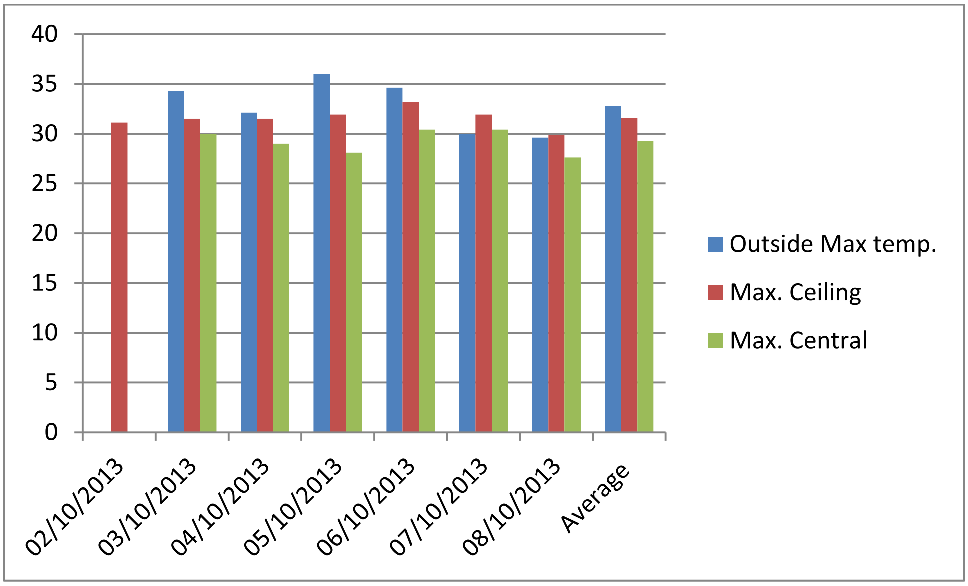


Table 50 shows that the outside maximum temperature was 36° C, the maximum ceiling temperature was 33.2° C and the central maximum temperature was 30.4° C. The average maximum temperatures for the outside, the ceiling and the central temperature from 2 October 2013 to 8 October 2013 ranged from 29.9°C to 34°C between 08:00 and 14:00 (outside – 32.8°C; ceiling – 31.6°C; inside - 29.3°C).

Table 51 Minimum outside/ceiling/central temperatures

Date	Outside Min temp.	Ceiling min.	Central min
02/10/2013	N/R	18.7	N/R
03/10/2013	25.8	19.4	27.8
04/10/2013	22.7	19.4	19.3
05/10/2013	25.1	20.2	20.4
06/10/2013	25.6	20.9	20.9
07/10/2013	18.8	19.8	20.2
08/10/2013	20.8	19.4	19.9
Average	**23.1**	**19.69**	**18.38**

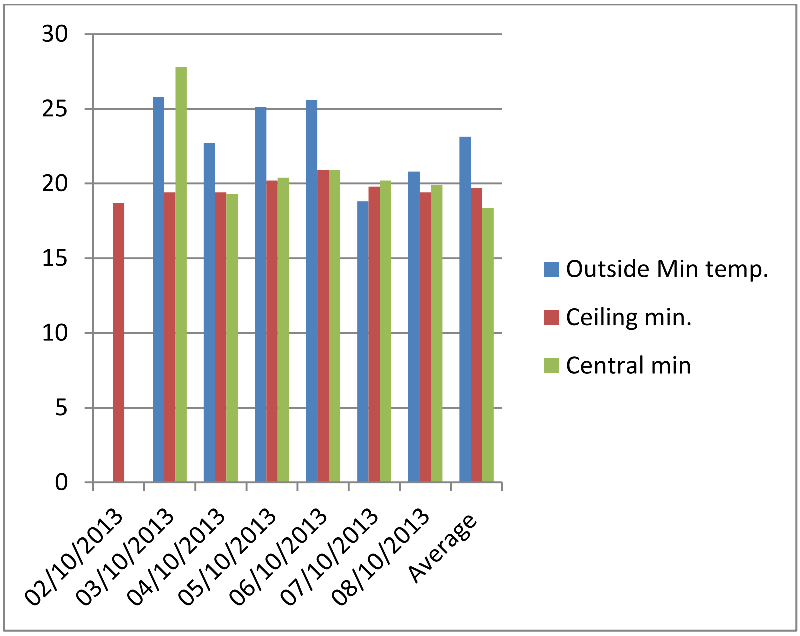


Table 51 shows that the outside minimum temperature was 18.8°C, the minimum ceiling temperature was 18.7°C and the central minimum temperature was 19.3°C. The average minimum temperatures for the outside, the ceiling and the central temperature from 2 October 2013 to 8 October 2013 ranges from 23.1°C to 34°C between 08:00 and 14:00. (Outside – 23.1°C; Ceiling – 19.7°C; Inside – 18.4°C.)

5.2.3.2 Discussion

The maximum outside temperature (36°C) maximum was greater than the internal temperature at the ceiling (31.6°C) by about 5.6°C and greater than the central temperature by 4.4°C. This means that the ceiling was trapping heat coming in from the outside through the roof resulting in the outside temperature (36°C) being reduced to 29.3°C internally.

The average minimum temperature outside (23.1°C) was more than the internal temperature (18.4°C) by 4.7°C. The internal low morning temperature conveys the possibilities that heat trapped by the ceiling was transferred to the internal air via convection then escaped via windows or infiltration resulting in fresh air flowing in.

Thermal comfort standards recommend that the ceiling radiant asymmetry be less than 5°C of the air temperature to avoid thermal discomfort. The ceiling temperature in the classroom was lower than the internal air temperature by less than 5°C; therefore, the learners should not experience thermal discomfort from heat coming from the ceiling.

Table 52 Average temperatures at desks (1-10)

Average temperature at desks	Desk 1	Desk 2	Desk 3	Desk 4	Desk 5	Desk 6	Desk 7	Desk 8	Desk 9	Desk 10	Average
Ave.min.temp	20.04	20.58	19.8	20.5	20.74	20.62	20.96	21.04	20.98	20.7	**20.596**
Ave.max.temp	29.6	29.7	30.86	29.4	30.1	29.88	30.02	29.76	29.18	30.22	**29.872**

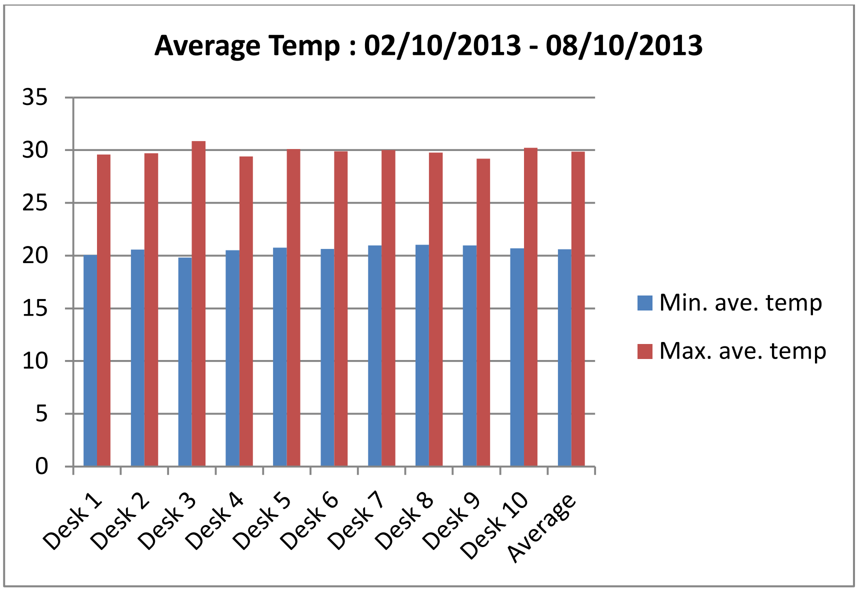


Table 52 shows that the average temperatures for the desks from 3 October 2013 to 8 October 2013 ranged from 20.6°C to 29.9°C between 08:00 and 14:00.

5.2.3.3 Discussion

The maximum temperatures recorded at all desks occurred on 6 October 2013 and 6 October 2013 (above 30°C). This is about 3° C greater than the temperature recommended by the thermal comfort standard. Outside temperatures were recorded at their highest on these dates (slightly above 34°C). The minimum temperature occurred on 2 October 2013. The temperatures at desk are slightly below and above the thermal comfort standard recommendations by ± 3°C.

5.2.3.4 Grade 5A Learner Thermal comfort perception

To measure the learners' perception of the thermal comfort, the grade 5 learners were asked to respond to two statements, that is, MY CLASSROOM IS HOT and MY CLASSROOM IS COLD through selecting one of five faces that describe agreement or disagreement with the statement. The five faces represent five scales but **do not** represent satisfaction; the scales 1, 0, -1 represent satisfaction. See table 23.

The classroom was divided into five sections for the location of learners to assess close proximity to walls/windows. In this classroom: Section A – close to wide window low facing south; sections B and C – the middle; and, sections D and E close to the wall with a high window facing north. See figure 39 below.

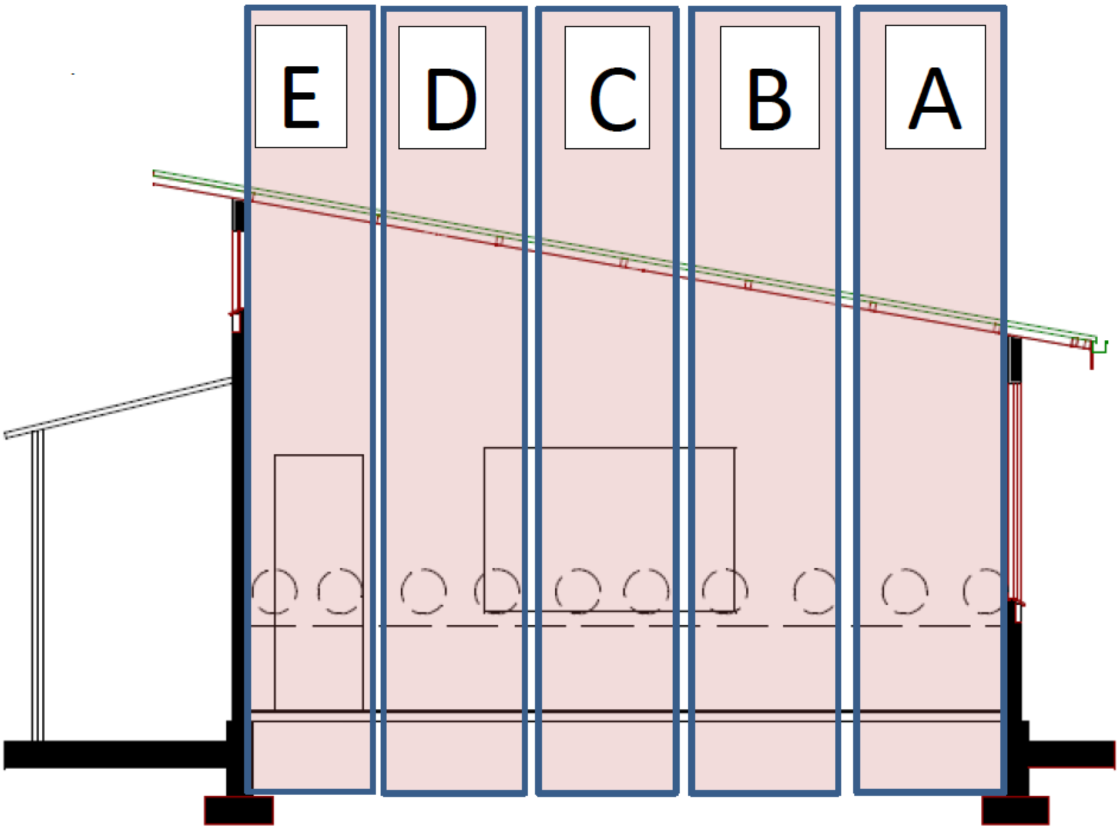


Figure 39 Section of classroom

Table 53 Thermal sensation response to 'MY CLASSROOM IS HOT' statement (13/09/2013)

SCALE	**Section A**	**Section B**	**Section C**	**Section D**	**Section E**
Sensation scale	***No. of Students***	***No. of Students***	***No. of Students***	***No. of Students***	***No. of Students***
2	5	5	8	4	5
1	3	-	2	2	1
0	1	1		1	2
-1	-	4		3	1
-2	1	-			2
	10	**10**	**10**	**10**	**10**

Table 53 shows that 50 learners participated in the survey taken in the morning (09:00) on 8 October 2013.

Section A: 5 learners strongly agreed that they were hot, 3 learners agreed that they were hot, 1 learner was OK and 1 learner disagreed with the statement.

Section B: 5 learners strongly agreed that they were hot, 1 learner was OK and 4 learners disagreed with the statement.

Section C: 8 learners strongly agreed that they were hot, 2 learners agreed that they were hot.

Section D: 4 learners strongly agreed that they were hot, 2 learners agreed that they were hot, 1 learner was OK and 3 learners disagreed with the statement.

Section E: 5 learners strongly agreed that they were hot, 1 learner agreed with the statement of being hot, 2 learners were OK, 1 learner disagreed with the statement and 2 learners strongly disagreed with the statement.

Table 54 Thermal sensation response to 'MY CLASSROOM IS COLD' statement

SCALE	Section A	Section B	Section C	Section D	Section E
Sensation scale	***No. of Students***	***No. of Students***	***No. of Students***	***No. of Students***	***No. of Students***
2	3	2	1	1	5
1	2	2	-	1	-
0	2	1	4	2	2
-1	2	4	2	3	3
-2	1	-		3	1
	10	**9**	**7**	**10**	**11**

Table 54 shows that 47 learners participated in the survey taken in the morning (09:00) on 13 September 2013.

Section A: 3 learners strongly agreed that they were cold, 2 learners agreed it was cold, 2 were OK, 2 disagreed it was cold and 1 strongly disagreed that it was cold.

Section B: 2 learners strongly agreed that they were cold, 2 learners agreed it was cold, 1 was OK, 4 disagreed that it was cold.

Section C: 3 learners strongly agreed that they were cold, 2 learners agreed it was cold, 4 were OK and 2 disagreed that it was cold.

Section D: 1 learner strongly agreed that they were cold, 1 learner agreed it was cold, 2 were OK, 3 learners disagreed it was cold and 3 strongly disagreed that it was cold.

Section E: 5 learners strongly agreed that they were cold, 2 were OK, 3 learners disagreed it was cold and 1 strongly disagreed that it was cold.

Table 55 Learner thermal comfort sensation to classroom warmth

Comfort level	Students
-2	5
-1	7
0	5
1	8
2	27
(blank)	1
Grand Total	**53**

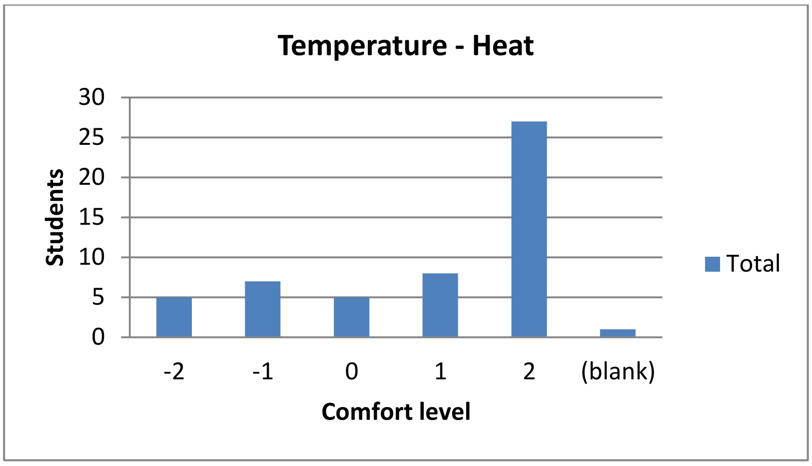


Table 55 shows the learners' thermal comfort sensations towards the warmth of the classroom. Out of the 53 grade 5 learners that participated in the research, 19 learners strongly agreed that they were hot, 7 learners agreed that they were hot, 9 learners were OK, 4 learners strongly disagreed with the statement. Of the 39 learners that participated in the research, 26 felt that they were hot.

It is assumed that 28% (20 out of 52) learners that voted - 1,0 and 1 were satisfied with the thermal conditions.

Table 56 Learner thermal comfort sensation to classroom coldness

Comfort level	Student
-2	14
-1	8
0	10
1	5
2	14
(blank)	2
Grand Total	**53**

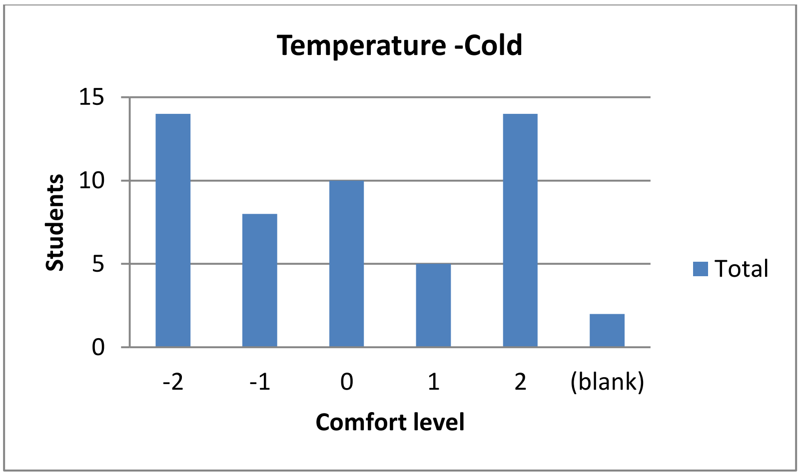


Table 56 shows the learners' thermal comfort sensations towards the coldness of the classroom. The majority of the learners (32) did not feel that the classroom was cold, but 19 learners agreed that it was cold.

It is assumed that 45% (23 out of 51) learners that voted -1, 0 and 1 were satisfied with the thermal conditions.

5.2.3.5 Discussion

The perception survey on heat in the classroom shows that 35 out of the 52 grade 5 learners that participated in the study felt that the classroom was hot. Only twelve (12) learners felt that it was not hot. Five (5) learners expressed neutrality.

The perception survey on cold in the classroom shows that 19 out of the 51 grade 5 learners that participated in the study felt that the classroom was cold. Only twenty-two (22) learners felt that it was not cold. Ten (10) learners expressed neutrality.

Table 57 Thermal sensations - warmth

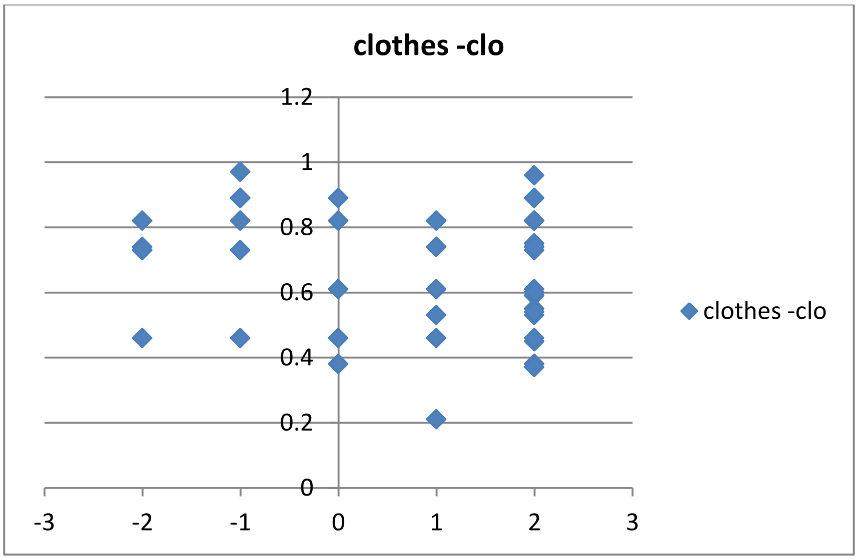
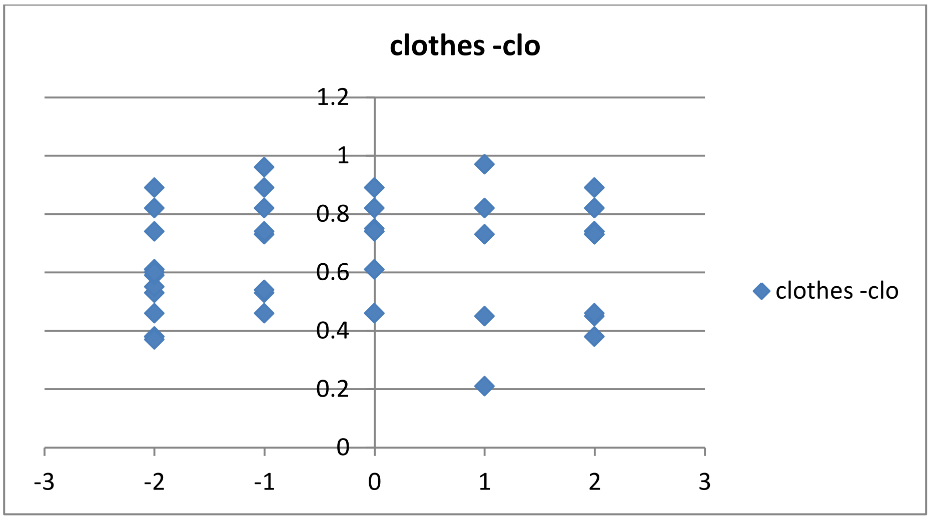


Table 58 Thermal sensations - coolness



Tables 57 and 58 show that the linear correlation is near zero, meaning that no relationship exists between what the learners are wearing and their thermal sensations. Therefore, the clothing insulation did not influence learners' thermal sensation.

5.2.4 **Grade 7A: 02/10/2013 - 08/10/2013**

The actual temperature data for grade 7A was collected for a week from 2 October to 8 October 2013 between 08:00 and 14:00. Data was collected outside, at the centre of the class and at learners' desks.

The data loggers were left at their positions for the duration of the study; hence, the study measured whole day temperatures (daytime and night-time, with and without occupancy, including weekends - 5 October 2013 and 6 October 2013).

Refer to addenda B for actual desk air temperature measurements.

(N/R indicates no reading recorded)

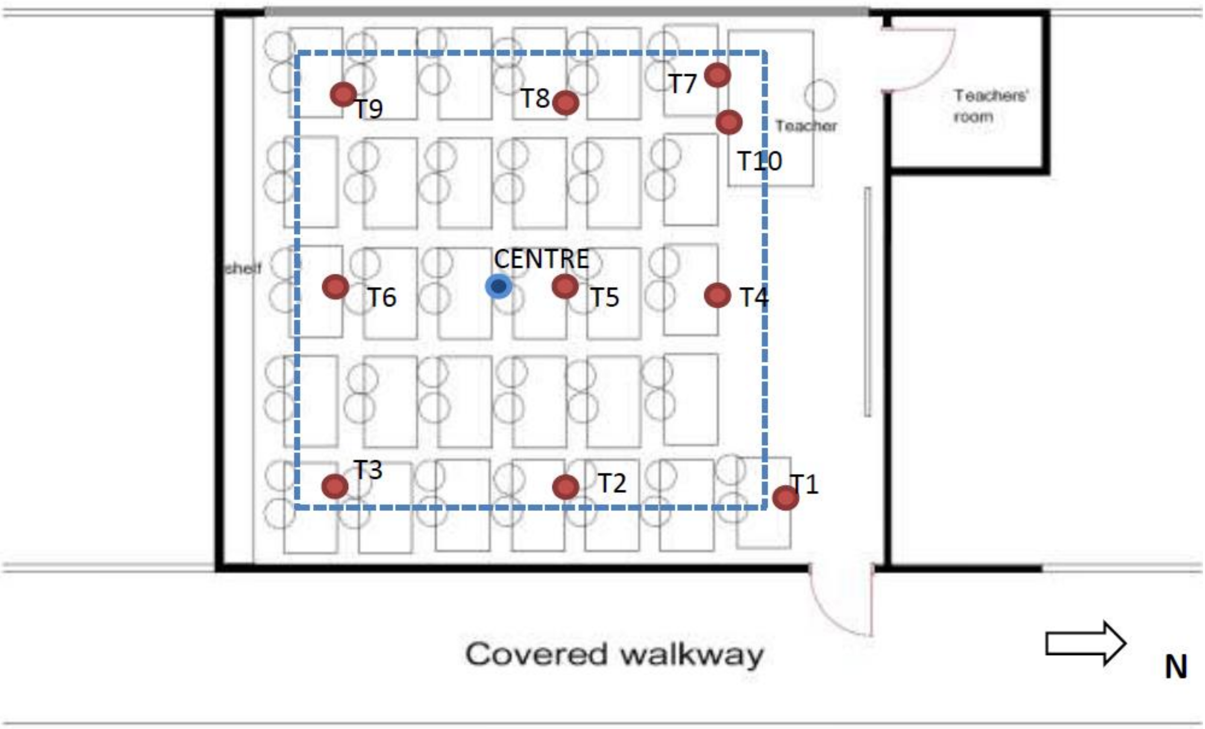


Figure 40 Location of loggers

5.2.5 Outside temperature

Table 59 Minimum & maximum outside temperatures

Outside temperature 08:00-14:00	Min temp.	Max temp.
03/10/2013	25.8	34.3
04/10/2013	22.7	32.1
05/10/2013	25.1	36
06/10/2013	25.6	34.6
07/10/2013	18.8	30
08/10/2013	20.8	29.6
Average	**23.1**	**32.76**

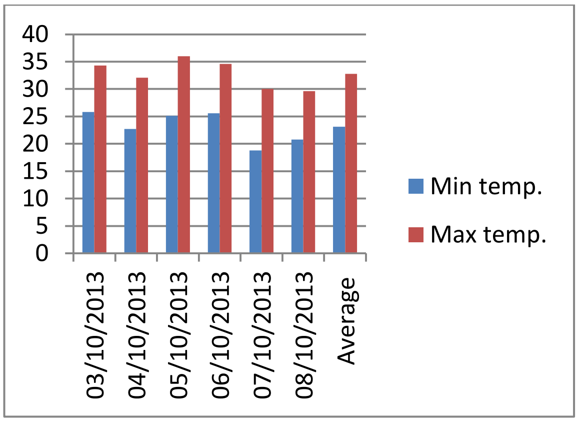


Table 59 show temperatures taken in the outside classroom from 3 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) outside was 18.8°C recorded on 7 October 2013. The maximum temperature (taken in the afternoon - 14:00) outside was 36°C on 5 October 2013. Temperature readings for 2 October 2013 were not recorded.The average for minimum and maximum temperatures for the outside temperature from 3 October 2013 to 8 October 2013 ranged from 23.1°C to 32.8°C between 08:00 and 14:00.

Table 60 Maximum and minimum ceiling temperatures

Ceiling temperature 08:00-14:00	Min temp.	Max temp.
02/10/2013	17.89	29.37
03/10/2013	20.4	N/R
04/10/2013	N/R	N/R
05/10/2013	N/R	N/R
06/10/2013	N/R	N/R
07/10/2013	N/R	N/R
08/10/2013	N/R	N/R
Average	**23.6**	

Table 60 shows temperatures taken in the classroom at the ceiling from 3 October 2013 to 8 October 2013 between 08:00 and 14:00. The only recording occurred on 2 October 2013 and the morning of 3 October 2013. The minimum temperature (taken in the morning - 08:00) outside was 17.9°C and the maximum temperature (taken in the afternoon - 14:00) outside was 29.4°C.The average temperature for the ceiling was 23.6°C between 08:00 and 14:00.

Table 61 Minimum & maximum central temperatures

Central temperature 08:00-14:00	Max temp.	Min. temp.
02/10/2013	N/R	N/R
03/10/2013	30.9	27.1
04/10/2013	29.7	19.7
05/10/2013	28	20.6
06/10/2013	29.8	21.3
07/10/2013	29.8	20.9
08/10/2013	26.7	19.9
Average	**23.13**	**29.15**

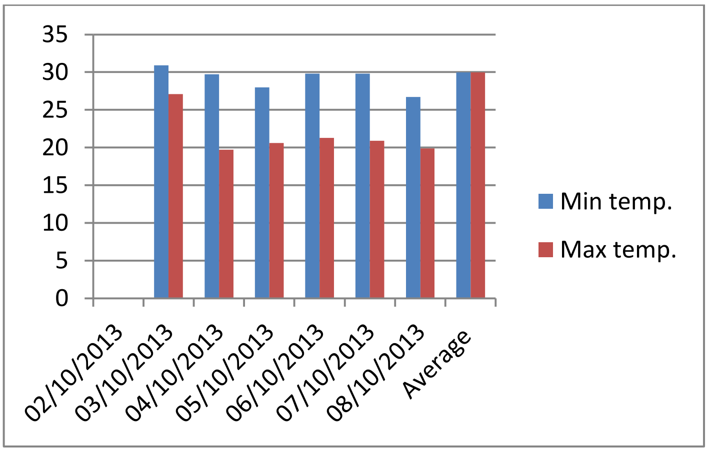


Table 61 shows temperatures taken from the centre of the classroom from 3 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum central temperature (taken in the morning -

08:00) was 19.7°C on 8 October 2013. The maximum temperature (taken in the afternoon - 14:00) centrally was 30.9°C on 3 October 2013. Temperature readings for 2 October 2013 were not recorded.The average for minimum and maximum temperatures for outside temperatures from 3 October 2013 to 8 October 2013 ranged from 23.13°C to 29.2°C between 08:00 and 14:00.

Table 62 Maximum outside & central temperatures

Date	Outside Max temp.	Max. Central
02/10/2013	N/R	N/R
03/10/2013	34.3	30.9
04/10/2013	32.1	29.7
05/10/2013	36	28
06/10/2013	34.6	29.8
07/10/2013	30	29.8
08/10/2013	29.6	26.7
Average	**32.76**	**29.15**

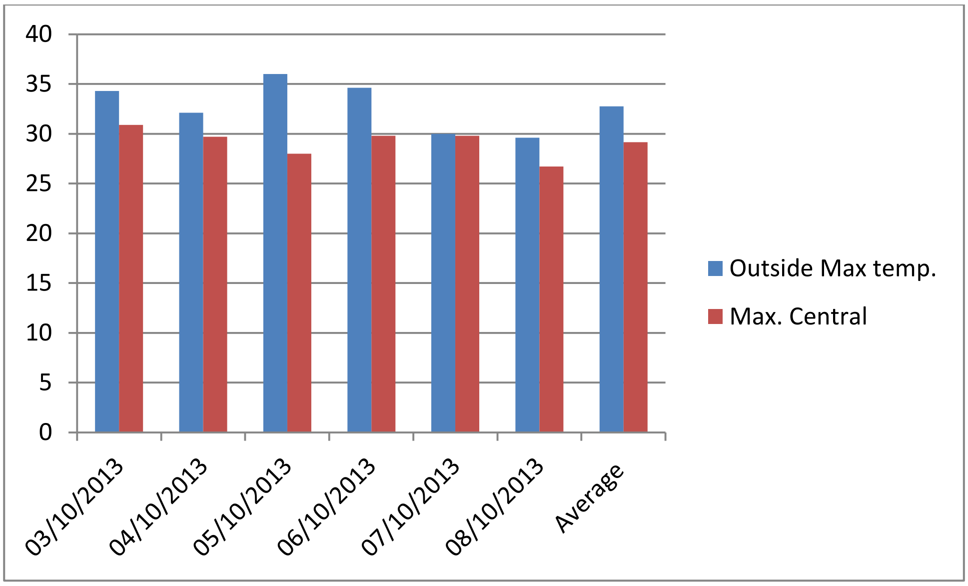


Table 62 shows that the outside maximum temperature was 36° C on 5 October 2013 and the maximum central temperature was 30.9°C on 3 October 2013. The average maximum temperatures for the outside and the central temperature from 2 October 2013 to 8 October 2013 ranged from 32.8°C to 29.2°C between 08:00 and 14:00.

Table 63 Minimum outside & central temperatures

Date	Outside Min temp.	Central min
02/10/2013	N/R	N/R
03/10/2013	25.8	27.1
04/10/2013	22.7	19.7
05/10/2013	25.1	20.6
06/10/2013	25.6	21.3
07/10/2013	18.8	20.9
08/10/2013	20.8	19.9
Average	**23.13**	**21.58**

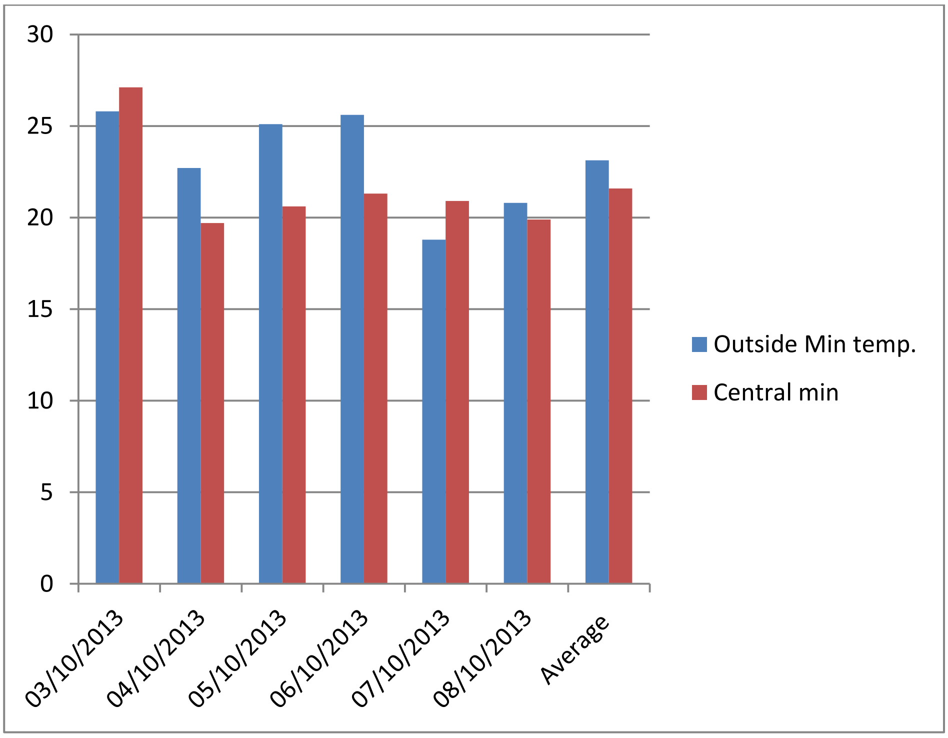


Table 63 shows that the outside minimum temperature was 18.8° C on 6 October 2013 and the minimum central temperature was 19.7°C on 4 October 2013.The average minimun temperatures for the outside and the central temperature from 2 October 2013 to 8 October 2013 ranged from 23.1°C to 21.6°C between 08:00 and 14:00.

5.2.5.1 Discussion

The maximum outside temperature was 36°C and it was greater than the maximum central temperature by about 8.9°C and greater than the ceiling temperature by 5.2°C. This means that the ceiling is trapping heat coming in from the outside through the roof resulting in the outside temperature being reduced to ±30°C internally.

The minimum temperature outside (23.1°C) was higher than the minimum ceiling temperature (17.9°C) by 5.2°C. The minimum central temperature (21.6°C) was lower than the outside minimum temperature by 1.5°C. (Ceiling measurements are limited)

The outside temperature gradually heats up the ceiling and internal spaces through the day. The internal space is also warmed up by heat generated by the learners. The high morning temperatures convey that the heat trapped by the ceiling was transferred to the internal air via convection and because the windows were closed after school the hot air remained trapped inside.

Thermal comfort standards recommend that the ceiling radiant asymmetry be less than 5°C of the air temperature to avoid thermal discomfort. The ceiling temperature in the classroom was lower than the internal temperature by less than 5°C therefore the learners should not experience thermal discomfort from heat coming from the ceiling.

Table 64 Average temperatures at desks

Average temperature at desks	Desk 1	Desk 2	Desk 3	Desk 4	Desk 5	Desk 6	Desk 7	Desk 9	Desk 10	Average
Ave. Min. temp	21.02	20.7	20.7	20.66	21.18	20.22	20.76	20.98	20.12	**20.704**
Ave Max. temp	28.5	28.4	30.36	29.84	30.18	29.34	29.52	29.18	28.98	**29.367**

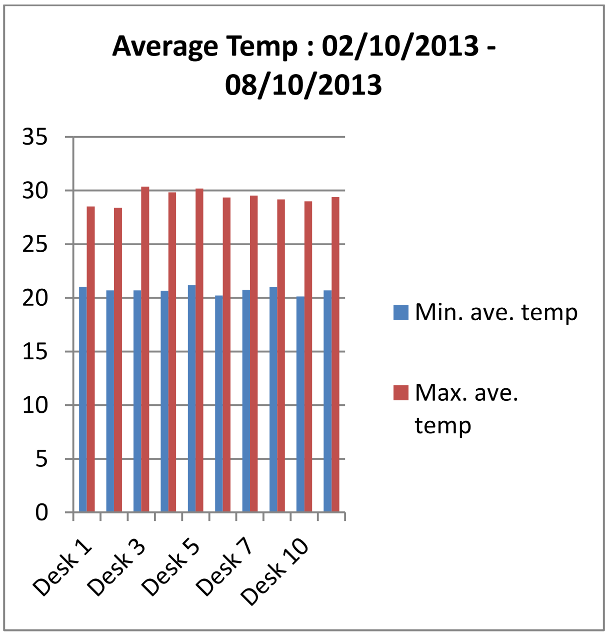


Table 64 shows that the average minimum and maximum temperatures for the outside and the central temperature from 23 October 2013 to 8 October 2013 ranged from 20.7°C to 29.4°C between 08:00 and 14:00.

5.2.5.2 Discussion

The maximum temperatures recorded at desks occurred on 4 October 2013, 6 October 2013 and 7 October 2013 with a temperature range of 26.7°C to 32.6°C. The maximum temperatures at the desks are above the recommended temperature range. Outside temperatures were recorded at their highest on these dates (slightly above 34°C). The temperatures at the desks are slightly below and above the thermal comfort standard recommendations by ± 5°C.

5.2.5.3 Grade 7A thermal comfort learner perception

To measure the learners' perception of the thermal comfort, the grade 7 learners were asked about their satisfaction levels regarding the temperature around their desks. The learners were asked to select the satisfaction level that best described their level of satisfaction. See table 32.

The location of learners and their close proximity to walls/windows was not observed. The learner survey was taken on the afternoon of 8 October 2013.

Table 65 Learner thermal satisfaction (08/10/2013)

Comfort level	Student
-2	19
-1	12
0	6
1	7
2	1
(blank)	4
Grand Total	**49**

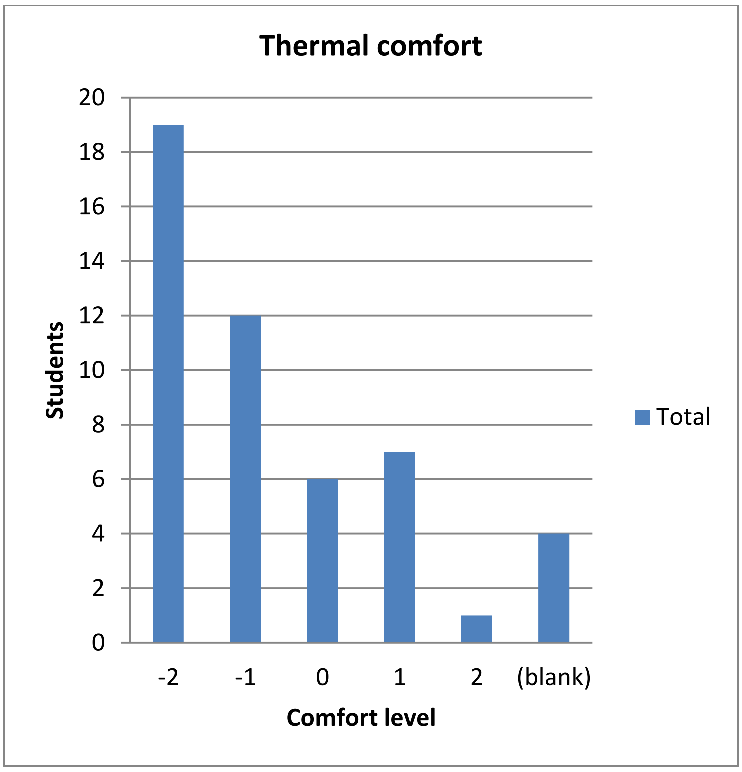


Table 65 shows the learners' thermal comfort sensations response. Of the 49 grade 7 learners that participated in the research, 8 learners were satisfied with the thermal conditions in the classroom, 6 expressed neutrality and 31 expressed discomfort. Overall the 14 learners out of 45 that responded were satisfied, that is a 31.1% thermal comfort acceptability level.

It is assumed that 55% (25 out of 45) of learners that voted -1, 0 and 1 were satisfied with the thermal conditions.

5.2.6 **Discussion**

The air temperature data collected at the desks of learners in Meetse-a-Bophelo primay school show that the maximum temperature fell outside the thermal comfort standards recommendations. The maximum air temperature deviated slightly from that recommended by ±1.5°C to 3°C. The average minimum temperature fell within the recommended range.

The varying temperatures in the classrooms may be affected by the location of classrooms on the site. For example, the grade 3 classroom has the highest air temperature because it is located on the east-south-east side the site and the maximum glazed window exposure faces the north direction. Whereas, the grades 5, 6 and 7 classrooms on the south east, east and west location of site have the maximum glazed window exposure facing the south east, east and west direction. Therefore they only experience medium and high temperatures in the morning before school starts and in the afternoon when school ends.

The actual daily outside temperature and the ceiling temperature was taken for this study. The daily temperature average for the school was used to compare temperatures and check the effect of the external temperature on intenal temperatures.The average maximum temperature for the duration of study ranged from 32.8°C to 34.3°C and the minimum temperature ranged from 23°C to 25°C.

The minimum internal temperature for the classrooms ranged from 16.5°C to 19.6°C and the maximum temperature ranged from 24.3°C to 31.9°C.

The comparison between the daily minimum temperature in the classroom and the daily minimum temperature average shows that the internal classroom temperature was lower by 6.5°C to 5.4°C. The daily maximum temperature in the classrooms compared to the external daily temperature show that it was higher by 2.4°C to 8.5°C.

Three classes completed the learner survey, that is grades 3, 5 and 7.The majority of the learners from grades 3 and 5 agreed that their classrooms were hot, while some learners agreed that they were cold. Sixty-nine percent of grade 7 learners expressed dissatisfaction with the classroom temperature.

The desk minimum and maximum temperature average was 19.1°C to 29°C. The minimum temperature was below the recommended range. Satisfaction was not measured for the grades 3 and 5, but thermal sensation was measured. Many learners expressed satisfaction with the thermal conditions in both grades,however 76% of the grade 5 learners expressed satisfaction with the thermal conditions although they experienced a minimum temperature below the recommended range.

The learners' uniform insulation was in most cases was within the 0.5cl range, with some slightly above and below. The clothing insulation rating did not affect the learners' thermal sensation.

The learners' activity levels were low resulting in low metabolic rates and low heat outputs.

6 Findings

The findings of this research discuss the usability of the LTCP after testing it on case studies and the relationship between the standards and learners' perception.

6.1 Findings addressing question 3

What does the data collected using the learner thermal comfort protocols indicate about the thermal comfort conditions and design of protocol?

The actual temperatures data collected for case study A and case study B indicate the following on thermal comfort conditions:

i. The actual air temperature in the classroom is not uniform; it varies at different locations in the classroom and is influenced by external temperatures.
ii. The actual air temperature in the classroom is lower than the external temperature, but does not fall within the recommended range.
iii. The actual air temperature in the classroom is also affected by crowding in the classrooms and the use and access of openings (windows and doors).
iv. Thermal insulation of clothing does not influence the learners' thermal perception.
v. The learners' level of activity can influence the learners' thermal comfort

The actual temperature data collected for case study A and case study B indicate the following on the design of protocol:

i. The occupied zone for naturally ventilated spaces is not required for the measurement of thermal comfort, but it is important to note where the measurement was taken because the surrounding elements can influence temperatures (for example close to a closed window).

ii. Radiant asymmetry is important for the determination of comfort.

iii. The correct measurement of vertical air temperature difference at the feet and head area is a challenge to measure at the centre of a dynamic space like a classroom. The loggers require uninterrupted locations within the classroom. Since the vertical air temperature was not properly taken at suggested points, the importance of recording vertical air temperature was not accounted for.

iv. The 5-point scale thermal sensation scale used to measure the learners thermal sensation was designed to assess how the learners felt about the temperature in their classroom and also other indoor environmental factors. Two types of questionnaire were developed for different age groups (see addenda A). The questionnaire for grades 3 to 5 recorded thermal sensation and the questionnaire for grades 6 to 7 recorded satisfaction.

The grades 3 to 5 questionnaire presented the learner with a statement of how the learner felt and the learner was requested to select a face that reflected agreement or disagreement with the statement. For example – 'MY CLASSROOM IS HOT!' was used as a statement and the face that had a happy face reflected agreement with statement and the one that reflected disagreement showed a sad face.

The learners were also presented with an opposite statement - 'MY CLASSROOM IS COLD!' and asked to select a face that reflected agreement or disagreement (see table 66 below).

TABLE 66 LEARNER THERMAL SENSATION QUESTIONS

My classroom is HOT!!

I strongly agree / 2	I agree / 1	It is Ok /0	I disagree /-1	I strongly disagree /-2
				

My classroom is COLD!

I strongly agree / 2	I agree / 1	It is Ok /0	I disagree /-1	I strongly disagree /-2
				

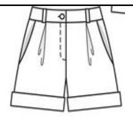
v. The grades 6 to 7 questionnaire asked the learners about their satisfaction level. The learners' thermal preference and acceptance should be included in the questionnaires to assess the ideal temperature for learners.

vi. Information on the learner clothing insulation was collected in the questionnaire. Learners were asked to select, draw or write down what they were wearing. The capturing of learners' clothing can be improved by presenting the learners with ensembles of clothing and a variation of school uniform types (see table 67 below).

Behavioural adaptability of the uniform by the learners for thermal comfort should be observed and recorded.

TABLE 67 CLOTHING INSULATION VALUE QUESTION

I am WEARING …

							Other
							

vii. Recording of perceptions is required to be conducted daily in the morning and in the afternoon so that temperatures affecting the learners can be related to actual recording at a specific time and location.

viii. Operation of the environmental controls and adaptation of the environment to suit thermal comfort should be recorded.

6.2 Findings addressing question 4

Is there a relationship between thermal comfort ASHRAE 55-2004 and ISO 7730-2005 standards recommendation with learners' perceptions?

The relationship was determined in three ways:

i. by comparing the total percentage of the learner vote for scales representing satisfaction, i.e. 1, 0 and -1 to the standards recommended percentages for acceptable indoor temperature, i.e. 80% and 90% acceptance;
ii. by comparing the actual temperature range with the recommended range;
iii. by comparing learners' perception actual vote with the recommended range.

Should the actual temperature fail to meet the recommended range, and consequently result in learners' perception of below 80% and 90% acceptance, then the relationship will exist.

Should the actual temperature meet the recommended range and consequently result in learners' perception below 80% and 90% acceptance, then the relationship does not exist.

6.2.1 ASHRAE 55 methods for the determination of acceptable thermal conditions

The ASHRAE 55 recommends methods to determine acceptable thermal conditions in spaces. The selected methods for this study are the following:

i. Method 1: The graphical method for typical indoor environments, i.e. psychometric "thermal comfort" chart / heat balance model; and,
ii. Method 2: The graphical method for naturally conditioned spaces, i.e. the adaptive model.

6.2.1.1 Method 1

The heat balance model is normally used in conditioned buildings rather than naturally conditioned buildings. The heat base model will be used in this instance because the general thermal comfort temperature range recommended by the standard for occupied buildings is drawn from this model, i.e. a temperature range of 22°C - 27°C. The ASHRAE 55 standard psychometric "thermal comfort" chart suggests that for occupants dressed in 0.5clo when it is warm outside the temperature range from ±23.5°C - ±28°C is recommended and for occupants dressed in 0.1clo when it cool outside, the temperature range from ±22°C - ±25°C is recommended. Failure of the buildings to meet the recommended range and the 80% occupant acceptability will result in the relationship being non-existent.

Application of method 1

The ASHRAE 55 standard psychometric "thermal comfort" chart (figure 41) for a typical indoor environment may be applied when the following criteria are followed:

i. Occupants have an activity level on 1.0 met – 1.3 met;
ii. Clothing worn provides 0.5 and 1.0clo thermal insulation;
iii. The PMV limits 0.5 (slightly cool and slightly warm) PPD 10% (see table 2);
iv. The relative humidity is from around 10% to around 70%.

The range of operative temperature presented in the chart below (figure 41) is for 80% occupant acceptability. This is based on 10% dissatisfaction criteria for whole body thermal comfort based on the PMV-PPD index and 10% dissatisfaction from local discomfort.

For the evaluation of case studies internal temperature, the temperature ±23.5°C - ±28°C will be used to check the occupants acceptance (see figure 41 highlighted area).

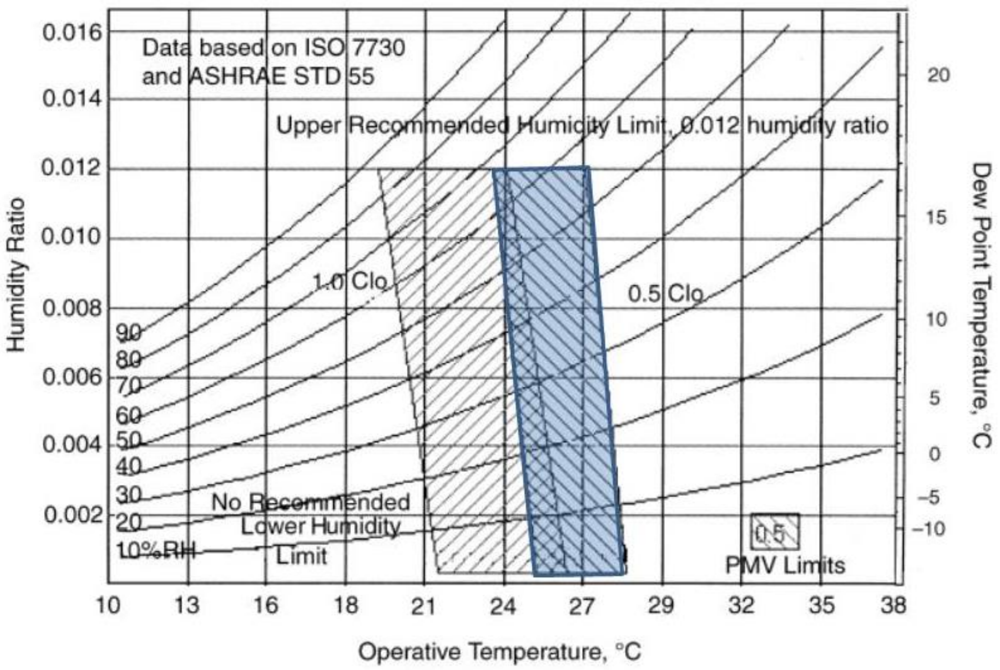


Figure 41 Typical indoor environment operative temperature chart

Actual temperatures on the typical indoor environment charts - Method 1

The average maximum air temperature for learners in case studies A and B that participated in the survey, are shown on table 68 below.

Table 68 Classroom maximum temperatures

Grade/Case study	Maximum temperature	Relative humidity
3/A	31.8	23%-70%
7/A	28.3	
3/B	29.8	
5/B	29.9	
7/B	29.4	

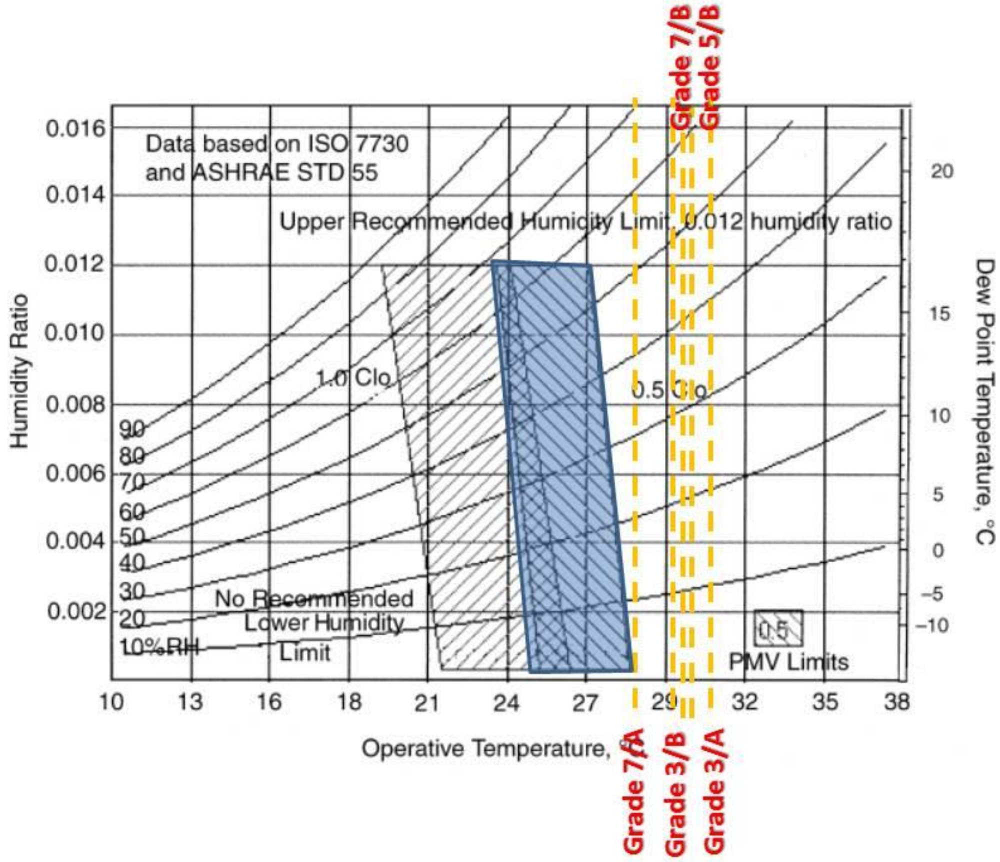


Figure 42 Actual maximum temperatures in case studies A & B

When actual temperatures are charted on the typical indoor environment operative temperature chart (figure 42), it shows that when the relative humidity ranges from 23% - 70% and the maximum temperature is 31.8°C in the grade 3 case study A, the indoor temperatures fall beyond the comfort zone; the temperature is 29.8°C in grade 3; and in case study B – the indoor temperatures also fall beyond the comfort zone. When the temperature is 28.3°C in grade 7 case study A, the indoor temperatures fall beyond the comfort zone; the temperature is 29.9°C in grade 5, case study B and so the indoor temperatures also fall beyond the comfort zone; and the temperature is 29.4°C in grade 7, case study B thus the indoor temperatures falls beyond the comfort zone.

The average minimum air temperature for learners in case studies A and B that participated in the survey, are shown in table 69 below.

Table 69 Minimum temperatures of case studies A & B

Grade/Case study	Minimum temperature	Relative humidity
3/A	21.6	
7/A	19.7	
3/B	20.1	
5/B	20.6	
7/B	20.7	23%-70%

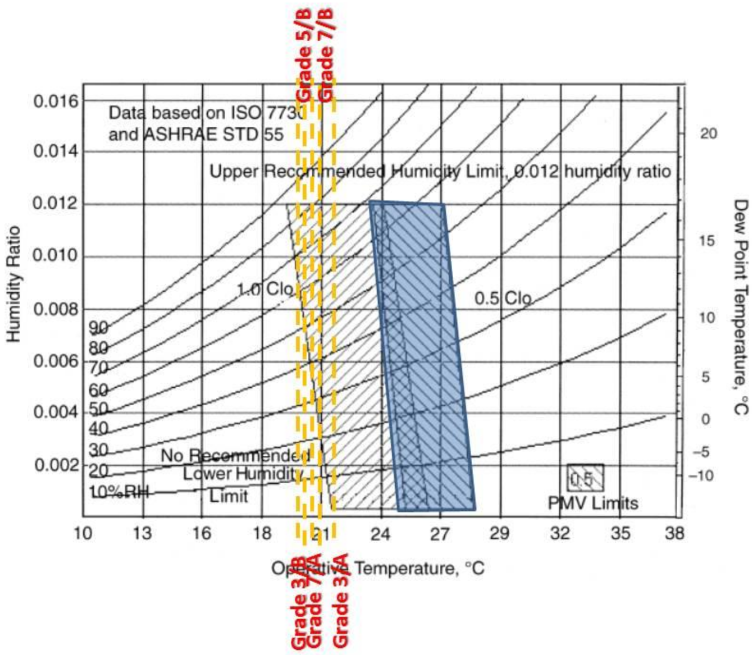


Figure 43 Actual minimum temperatures in case studies A & B

When actual minimum temperatures are charted on the typical indoor environment operative temperature chart (figure 43), it shows that when the relative humidity ranges from 23% - 70%, the minimum temperature falls below the recommended range. The temperatures in grade 3 (21.6°C), case study A, in grade 3 (20.1°C) in case study B, in grade 7 (19.7°C) case study A, grade 5 (20.6°C) case study B and grade 7 (20.7°C) case study B fall within the comfort zone for cool external conditions and clothing insulation 1.0 clo.

The temperatures for both case studies fall outside the recommended summer temperature range.

Learners' perception and satisfaction percentage in relation to the ASHRAE 55 – Method 1

Table 70 Learners' perception in relation to the heat balance model

Grade/ Case study	Maximum temperature	Minimum temperature	Relative humidity	ASHRAE Comfort zone			Learners ' perception				
				IN	OUT	Scale	2	1	0	-1	-2
3/A	31.8	21.6	23%-70%	All maximum temperature are outside comfort zone		Hot	8/28 (29%)	3/28 (21.4%)	11/28 (44%)	3/28 (11%)	3/28 (10.7%)
								71% Satisfaction			
						Cold	5/25 (20%)	1/25 (4%)	14/25 (50%)	3/25 (12%)	2/25 (16%)
								80% Satisfaction			
3/B	29.6	20.1					SURVEY TAKEN 3 DAYS LATER : NOT APPLICABLE				
5/B	29.9	20.6				Hot	27/52 (52%)	8/52 (15%)	5/52 (9.6%)	7/52 (13.5%)	5/52 (9.6%)
								48% Satisfaction			
						Cold	2/51 (3.9%)	5/51 (9.8%)	10/51 (19.6%)	8/51 (15.7%)	14/51 (24.5%)
								48% Satisfaction			

Grade / Case study	Max. temperature	Min. temperature	Relative humidity	ASHRAE Comfort zone		Learners ' perception					
				IN	OUT	Scale	2	1	0	-1	-2
7/A	28.3	19.7	23%-70%	All minimum temperature are outside comfort zone for warm outside temperatures			10/31 (32.3%)	5/31 (16.1%)	4/31 (12.9%)	4/31 (12.9%)	8/31 (25.8%)
								41%			
7/B	29.4	20.7					1/45 (2.2%)	7/45 (15.5%)	6/45 (13.3%)	12/45 (26.7%)	19/45 (42.2%)
								55.6%			

Table 70 shows that the actual indoor temperature in both case studies failed to meet the standards recommendation and the learners' satisfaction percentage is lower than the 80% recommended. Therefore there is a relationship between the standards and learners' perception.

Learners' perception actual vote in relation to the ASHRAE 55 – Method 1

Case study A: Grade 3

Sixty percent of the learners in grade 3 responded that they were hot and 48% responded that they were cold, 23% learners were neither hot nor cold and 47% said they were OK.

In relation to the ASHRAE 55 chart, the maximum temperature (31.8°C) that the learners experienced was beyond the comfort zone and the minimum temperatures (21.6°C) were below the comfort zone.

Therefore, based on comparing both results there is relationship between the grade 3 learners' perception and the ASHRAE 55 standard.

Case study A: Grade 7

Forty-eight percent of the learners in grade 7 responded that they were satisfied, 38% were not satisfied and 12% were OK.

In relation to the ASHRAE 55 chart, the maximum temperature (28.3°C) that the learners experienced fell outside the comfort zone and the minimum temperature (19.7°C) fell below the comfort zone.

Therefore, based on comparing both results there is relationship between the grade 7 learners' perception and the ASHRAE 55 standard.

Case study B: Grade 3

The majority of the learners in grade 3 responded that they were hot while some felt that they were cold.

In relation to the ASHRAE 55 chart, the maximum temperature (29.8°C) that the learners experienced fell beyond the comfort zone and the minimum temperature (20.1°C) fell within the comfort zone that could be comfortable if the learners were wearing 1.0clo clothing insulation.

Therefore, based on comparing both results there is a relationship between the grade 3 learners' perception and the ASHRAE 55 standard. (It is possible that the learners that expressed that they were cold were wearing clothing with insulation below 0.1clo or were located close to open windows allowing air flow of more than 0.2 m/s.)

Case study B: Grade 5

The majority of the learners in grade 5 responded that they were hot when asked if they were hot and a majority felt that they were not cold when asked if they were cold.

In relation to the ASHRAE 55 chart, the maximum temperature (29.9°C) that the learners experienced fell beyond the comfort zone and the minimum temperature (20.6°C) fell below the comfort zone.

Based on comparing both results, the relationship between the grade 5 learners' perception and the ASHRAE 55 standard does not exist when the learners expressed that they were neither cold or hot (neutrality).

Case study B: Grade 7

About 69% of the learners in grade 7 responded that they were dissatisfied the temperatures in the classroom.

In relation to the ASHRAE 55 chart, the maximum temperature (29.4°C) that the learners experienced fell beyond the comfort zone and the minimum temperature (20.7°C) fell below the comfort zone.

Therefore, based on comparing both results there is a relationship between the grade 7 learners' perception and the ASHRAE 55 standard.

Conclusion on method 1

Based on the case studies discussed, a relationship between the learners' perception and the ASHRAE 55 standard (heat balance model) does exist. The actual temperatures failed to meet the recommended range and consequently resulted in learners' perception being below 80% and 90% acceptance.

6.2.1.2 Method 2

Application of method 2

The graphical method for naturally conditioned spaces applies to spaces with no mechanical ventilation and where the occupants activity level ranges from 1.0 to 1.3 met. The occupants must be able to adapt their clothing to indoor conditions. The adaptive chart below (figure 44) has two sets of operative temperature limits, i.e. 80% and 90% acceptability. The chart accounts for both thermal discomfort and occupants' clothing. The acceptable range of indoor temperature is related to the mean monthly outdoor air temperatures.

The recommended temperature range for CoT in September, with the monthly mean temperature at 19°C, is ±20.1°C - ±27°C and will achieve 80% occupant acceptability; and ±21°C – ±26.2°C will achieve 90% occupant acceptability. For October the monthly mean temperature is 21°C and temperatures ranging from ±21°C - ±27.8°C will achieve 80% occupant acceptability and temperatures ranging from ±22°C – ±27°C achieve 90% occupant acceptability (See figures 45 and 46).

Failure of the buildings to meet the recommended range and the 80% and 90% occupant acceptability will result in the relationship being non-existent.

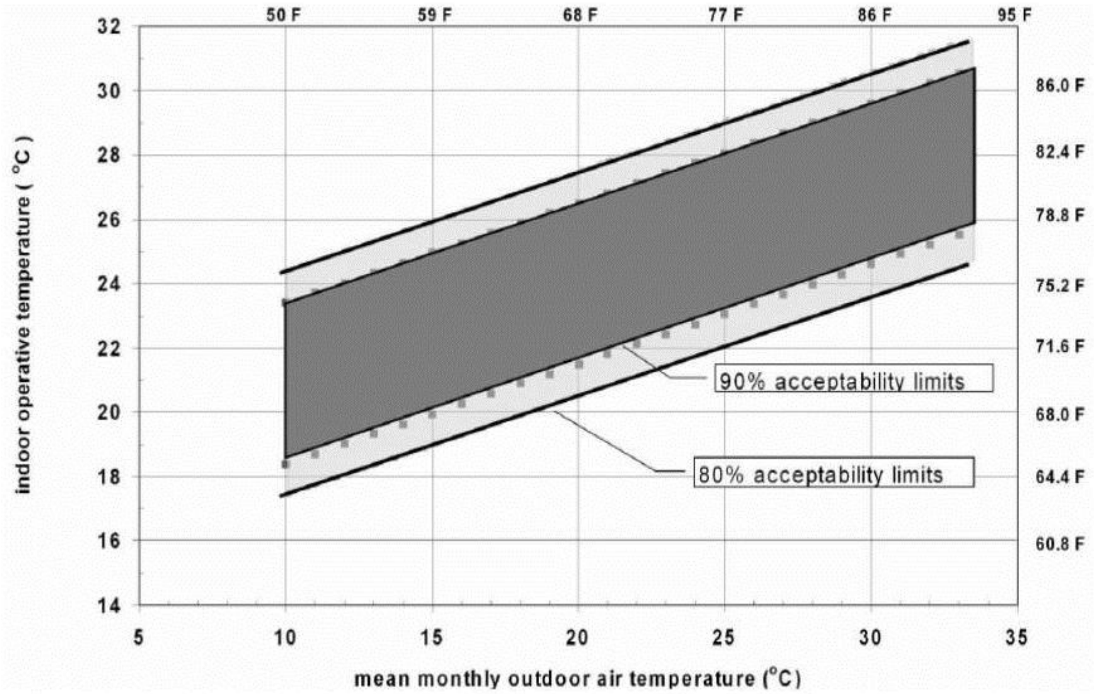


Figure 44 The adaptive chart

Actual temperatures on the adaptive charts – Method 2

Table 71 Minimum & maximum temperatures for case studies A & B

Case study A			Mean monthly temperature
Grade	Minimum average	Maximum average	September ±19
3	21.6	31.8	
5	20.3	27.9	
6	20.1	27.9	
7	19.7	28.3	
Case study B			
Grade	Minimum average	Maximum average	October ± 21
3	20.1	29.8	
4	19.5	29.7	
5	20.6	29.9	
7	20.7	29.4	

Table 71 shows the minimum and maximum indoor temperature and monthly mean temperatures for case studies A and B.

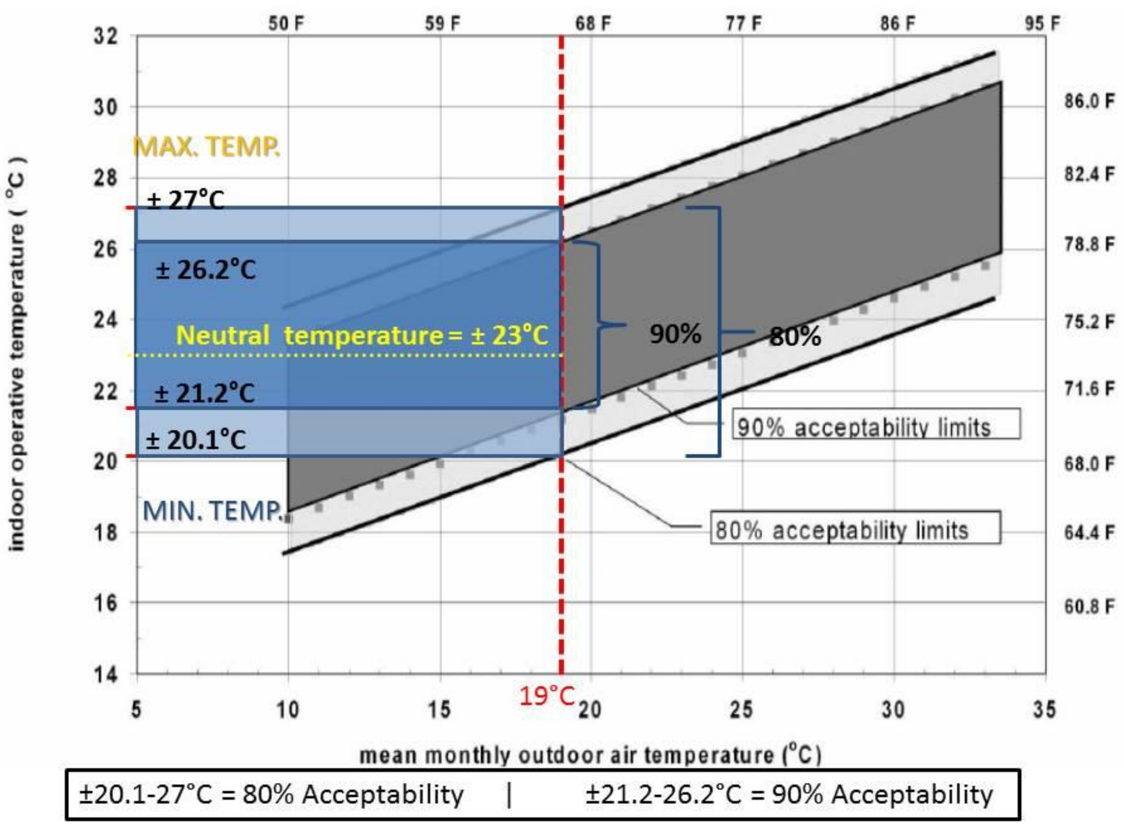


Figure 45 Case study a on adaptive chart

Figure 45 shows the acceptable minimum and maximum indoor temperatures in relation to the monthly mean temperature for September (19°C) in case study A. Temperatures ranging from ±20.1°C - ±27°C achieve 80% acceptability and temperatures ranging from ±21 ° C – ±26.2 ° C achieve 90% acceptability.

Grade 3 minimum temperatures achieve 90% acceptability, whereas grades 5, 6 and 7 failed to achieve acceptability. Grades 5 and 6 maximum temperatures achieve 90% acceptability, grade 7 achieve 80% acceptability and grade 3 fail to achieve acceptability.

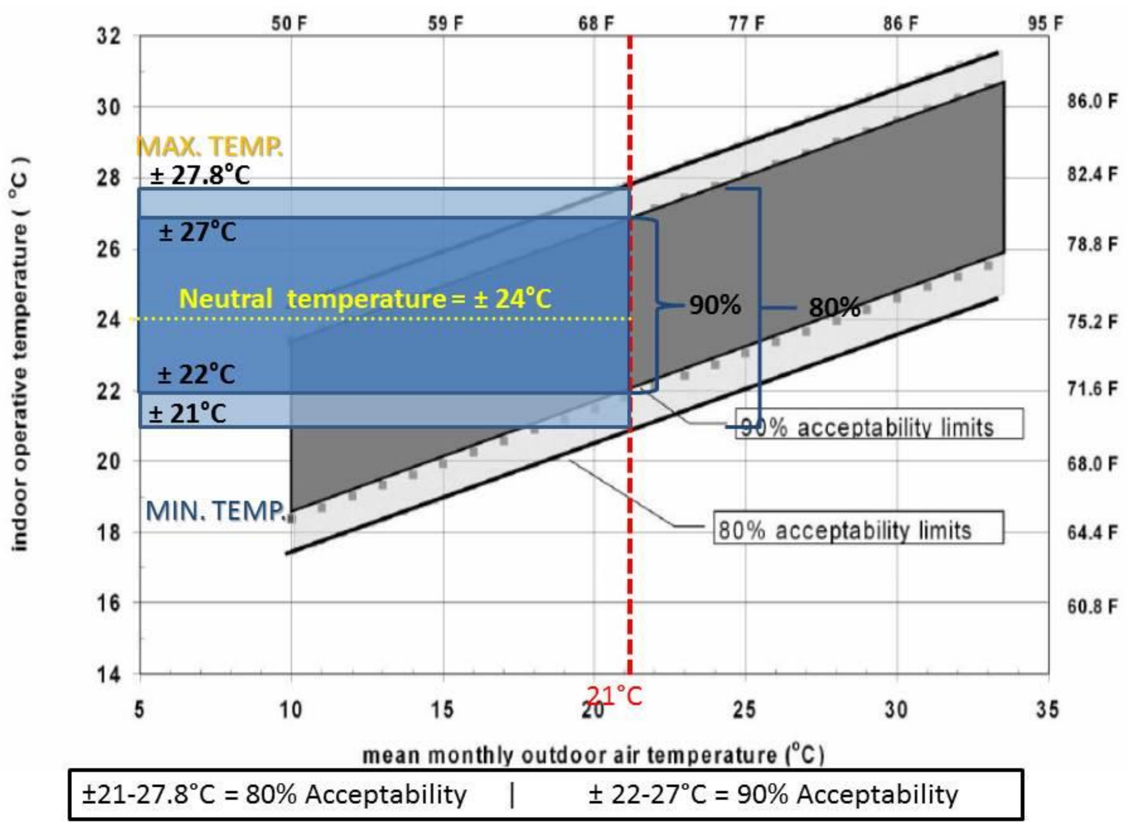


Figure 46 Case study b on adaptive chart

Figure 46 shows that the acceptable minimum and maximum indoor temperatures in relation to the monthly mean temperature for October (21°C). Temperatures ranging from ±21°C - ±27.8°C achieve 80% acceptability and temperatures ranging from ±22 ° C – ±27 ° C achieve 90% acceptability.

Grade 3 indoor minimum temperatures achieve 80% acceptability and grades 4, 5 and 7 temperatures fail to achieve acceptability. Grades 5 and 7 maximum temperatures achieve 90% acceptability whereas grades 3 and 4 fail to achieve acceptability.

Learners' perception in relation to the ASHRAE 55 – Method 2

Case study A: Grade 3

Thermal sensation - Hot

Section A		Section B		Section C		Acceptability	
Sensation scale	*No. of Students*	*Sensation scale*	*No. of Students*	*Sensation scale*	*No. of Students*	*Max. temp.*	*0%*
2	4	2	-	2	4	29.9°C	None(Above range)
1	2	1	-	1	1		
0	4	0	6	0	1		
-1	2	-1	3	-1	-		
-2	2	-2	-	-2	1		
	14		**9**		**7**		

Thermal sensation - Cold

Section A		Section B		Section C		Acceptability	
Sensation scale	*No. of Students*	*Sensation scale*	*No. of Students*	*Sensation scale*	*No. of Students*	*Min. temp.*	*90%*
2	1	2	2	2	2	20.6°C	± 21°C – ±26.2 ° C
1	-	1	-	1	1		
0	5	0	5	0	4		
-1	3	-1	-	-1	-		
-2	-	-2	2	-2	-		
	9		**9**		**7**		

Some learners in grade 3 responded that they felt hot and some responded that they were cold but the majority were neither hot nor cold.

In relation to the ASHRAE 55 Adaptive chart, the maximum temperature (31.5°C) that the learners experienced failed to achieve acceptability and the minimum temperature (21.6°C) achieved 90% acceptability.

Table 70 shows that the learners' actual votes for the scale -1, 0 and 1 on the sensation scale resulted in 80% satisfaction. The percentage of satisfied learners is lower than the predicted 90% acceptability.

Based on comparing both results, a relationship between the grade 3 learners' perception and the ASHRAE 55 Adaptive standard does not exist.

Case study A: Grade 7

Section A		Section B		Section C		Acceptability	
Satisfaction scale	***No. of Students***	***Satisfaction scale***	***No. of Students***	***Satisfaction scale***	***No. of Students***	***Max. & Min. temp. vs. %***	
2	4	2	3	2	3	18.9°C = 0%	27.1°C = 80%
1	3	1	2	1	-		
0	1	0	1	0	2		
-1	1	-1	2	-1	1		
-2	1	-2	3	-2	4		
	10		**11**		**10**		

Almost 50% of the learners in grade 7 responded that they were satisfied.

In relation to the ASHRAE 55 Adaptive chart, the maximum temperature (27.1°C) that the learners experienced achieved 80% acceptability and the minimum temperature failed to achieve acceptability.

Table 70 shows that the learners' actual votes for the scale -1, 0 and 1 on the sensation scale resulted in 41% satisfaction. The percentage of satisfied learners is lower than the predicted 80% acceptability.

Based on comparing both results, a relationship between the grade 7 learners' perception and the ASHRAE 55 Adaptive standard does not exist.

Case study B: Grade 3

Grade 3 thermal sensation was excluded because the learner survey was taken three days after the actual data was recorded.

Case study B: Grade 5

Thermal sensation – Hot

SCALE	Section A	Section B	Section C	Section D	Section E	Acceptability	
Sensation scale	***No. of Students***	***No. of Students***	***No. of Students***	***No. of Students***	***No. of Students***	***Max. temp.***	***%***
2	5	5	8	4	5	29.9°C	
1	3	-	2	2	1		
0	1	1		1	2		
-1	-	4		3	1		
-2	1	-			2		
	10	**10**	**10**	**10**	**10**		

Thermal sensation - Cold

SCALE	Section A	Section B	Section C	Section D	Section E	Acceptability	
Sensation scale	***No. of Students***	***No. of Students***	***No. of Students***	***No. of Students***	***No. of Students***	***Min. temp.***	***%***
2	3	2	1	1	5	20.6°C	80%
1	2	2	-	1	-		
0	2	1	4	2	2		
-1	2	4	2	3	3		
-2	1	-		3	1		
	10	**9**	**7**	**10**	**11**		

The majority of the learners in grade 5 responded that they were hot when asked if they were hot and a majority felt that they were not cold when asked if they were cold.

In relation to the ASHRAE 55 adaptive chart, the maximum temperature (29.9°C) that the learners experienced achieved no acceptability and the minimum temperature (20.6°C) achieved 80% acceptability.

Table 70 shows that the learners' actual votes for the scale -1, 0 and 1 on the sensation scale resulted in 48% satisfaction. The percentage of satisfied learners is lower than the predicted 80% acceptability.

Based on comparing both results, a relationship between the grade 7 learners' perception and the ASHRAE 55 Adaptive standard does not exist.

<u>Case study B: Grade 7</u>

Satisfaction scale	Student no.	Min. & Max temp. vs Acceptability	
-2	19	20.7°=80%	29.4°C=0%
-1	12		
0	6		
1	7		
2	1		
(blank)	4		
Grand Total	**49**		

About 63% of the learners in grade 7 responded that they were dissatisfied with the temperatures in the classroom.

In relation to the ASHRAE 55 chart, the maximum temperature (29.4°C) and the minimum temperature (20.7°C) that the learners experienced both failed to achieve acceptability.

Table 70 shows that the learners' actual votes for the scale -1, 0 and 1 on the sensation scale resulted in 55.6% satisfaction.

Based on comparing both results, a relationship between the grade 7 learners' perception and the ASHRAE 55 Adaptive standard does exist.

Conclusion on method 2

Based on the case studies discussed, a relationship between the learners' perception and the ASHRAE 55 adaptive standard is unclear when actual votes are used to determine satisfaction but when the scales -1, 0 and 1 are interpreted to represent satisfaction a relationship can be seen.

It is possible that satisfaction levels of 80% and 90% could have been reached when the classroom temperature was neutral (±23°C in case study A and ±24°C in case study B).

This study concludes that learners' temperature satisfaction may be influenced by other unmeasured factors, such as clothing insulation, location and clustering in class.

6.2.2 **Conclusion**

A relationship does exist between the learners and ASHRAE 55 standard.

7 Discussion

This study aimed to assess the indoor thermal condition of classrooms occupied by children using the learner thermal comfort protocol (LTCP). The classrooms were evaluated to assess if they met the narrow ASHRAE 55 Standard temperature range recommendations of 22°C - 27°C and context (CoT) related temperatures from the adaptive model, i.e. 20°C - 27°C.

This study found that most of the minimum temperatures experienced by the learners fell within the recommended temperature range and was accepted by most learners. The maximum temperatures experienced by learners fell outside the recommended temperature range and were accepted by some learners. However, the learners also showed a low satisfaction percentage related to the indoor temperature. This finding is significant because it concurs with literature research findings that learners' acceptance of temperatures above the recommended range is common in warm climate regions and that the Standard's narrow temperature range used to assess thermal comfort may not be suitable for warm climates.

The application of the LTCP in this research has found that the ASHRAE 55 Standard has not addressed a number of factors that impact on the research method for naturally conditioned buildings such as:

i. the variation of temperature within space and time in natural conditioned spaces. The non-uniformity in the physical environment discredits the application of the concept of the comfort zone;
ii. context related factors that contribute to thermal discomfort, i.e. overcrowding, the use of space, interior layout , the operation of environmental controls and culture; and,

iii. the definition of comfort related terms such as acceptability, satisfaction and preference. These terms are not clearly defined by the Standards and the criteria for measurement and interpretation is not discussed. This has resulted in the research creating its own definitions so that the data can be interpreted and analysed.

The Standards need to go beyond the recommendation of general temperature ranges to include contextual issues that affect thermal comfort such as culture and the interaction of occupants with other indoor environment factors (i.e. lighting, air quality and acoustics).

In the course of applying the LTCP, it was found school environments are controlled by teachers or the administration body. The learners in the classroom have restricted control of their environment through building restrictions (windows and door control, interior layout, seating, etc.) and culture restrictions (dress code, school administrative operation such as break time, circulation/movement). Research has shown that lack of control over one's environment may affect one's level of comfort and satisfaction.

Introducing flexibility in the administration of the school and empowering learners to control their environment may be important factors in achieving thermal comfort in addition to evaluating the indoor environment based on a narrow temperature range.

Learners can be empowered to adjust their environment to suit their thermal comfort through installing a temperature logger that warns learners of unacceptable temperatures in class, hence allowing the learners to operate environmental controls.

The learners and the teachers can be empowered in terms of operating buildings for the achievement of comfortable and conducive learning environments through documenting environmental factors that contribute to comfort or discomfort in a building user manual.

Flexibility in a school environment can be introduced through the administrative operation and culture of schools, such as avoiding overcrowding and allowing adequately spaced desk layouts to eliminate ‘heat pockets’ in classrooms; introducing flexibility in the teaching program such as starting school early in the summer months to avoid the discomfort of overheating in the afternoons and starting school late in the winter month to avoid the discomfort of cold mornings; allowing learners to change classrooms so that the classroom can ‘flush-out’ the heat generated by the warm bodies; and, finding opportunities to teach outside during hot days.

Having control of the occupied space, such as having the opportunity to adapt one’s environment and behaviour, has been seen as a contributor to achieving thermal comfort. However, the study of learners’ control of their environment was not included in the LTCP.

In the analysis of the LTCP case study surveys, it was found that the survey should have included questions relating to satisfaction, preference and acceptability in order to assess learners’ thermal perception. The questionnaires should have recorded learners’ thermal comfort daily and frequently during the day so that the findings could be related to the actual data recordings. The questionnaires should also record the specific locations of learners so that the measurements and perception can be related to the learners’ micro–context/climate. This could result in a correlation study between the learners’ perceptions and actual temperature data at the specific location and time.

The interpretation of thermal perception data has revealed that there are two ways of interpreting data thermal sensation votes. One is a direct interpretation of data and the other is by following the common research assumption of the numerical value of votes, i.e. -1, 0 and 1 on the thermal sensation scale representing ‘satisfaction’, ‘preference’ and ‘neutrality’.

This study has followed both ways of interpretation and has resulted in the interrogation of the design and objective of questionnaire, i.e. Is the aim to record exactly what the learners felt (actual votes) or to make general assumption though satisfaction votes? Which interpretation is correct?

The LTCP case study surveys captured learners' perception of other indoor environment factors such as lighting, acoustics and air quality as well as factors that affect learners' learning processes such as access to learning material and food. The findings were not analysed in this study but can give insight on issues that affect learners in schools.

Going forward, the LTCP will be required to be improved by including issues raised in the discussion.

8 Conclusions and recommendations

8.1 Conclusions

The testing of the LTCP on case studies has resulted in the analysed data proving the hypothesis to be correct. The hypothesis stated that ordinary primary school classrooms did not meet thermal comfort standards temperature recommendations. This statement is correct because the actual air temperature in the classroom did not fall within the narrow ASHRAE 55 standard temperature range recommendations of 22°C - 27°C and the context (CoT) related temperature range from the adaptive model, i.e. 20°C - 27°C.

The results from the case studies also show that the thesis statement predicting that the temperature in the primary schools was above 25.0°C was correct; however, the research did not find that the temperatures above 25.0°C affected the learners' health, wellbeing and productivity.

The assessment of LTCP developed from the ASHRAE standards concepts concludes that the adaptive model temperature range may be preferable in evaluating thermal comfort than the heat balance model in naturally ventilated spaces because it considers the impact of external temperature on the internal spaces and has a broader temperature range.

However, caution must be taken when using the adaptive model as a prescriptive tool for determining internal temperatures. The LTCP using the adaptive model must be developed further to record other aspects such as the building type, building design, and the building thermal mass, the use of building, the demographics, learners' behavioural adaptability and culture of school, and the impact of other indoor environment factors (i.e. lighting, air quality and acoustics).

8.2 Recommendations

The following recommendations are on how the Learner Thermal Comfort Protocol (LTCP) can be developed further by researchers and how research on thermal comfort in naturally ventilated classrooms can be taken further. The recommendations also include how the LTCP can be developed further to benefit the Department of Basic Education.

8.2.1 Recommendations to researchers

The following recommendations are given to similar thermal comfort research using the LTCP for the assessment of naturally conditioned school buildings:

i. The LTCP can be developed further by including thermal environment parameters excluded in this protocol, such as air flow and radiant temperature;

ii. The LTCP survey can be expanded to record the learners' preference, acceptance and satisfaction level of all the environmental factors (i.e. temperature, lighting, air quality and acoustics);

iii. The LTCP can be developed further by including recordings of other aspects such as the building type, building design, and the building thermal mass, the use of building, the demographics, learners' behavioural adaptability and culture of the school;

iv. The LTCP can be improved by recording the perceptions of learners and actual data simultaneously so that the learners' perceptions can be related to actual temperature data at the specific location and time, resulting in a correlation study.

The following recommendations are given to similar thermal comfort research in naturally conditioned school buildings:

i. Further research can be conducted to study the learners' adaptive behaviour, e.g. taking off layers of clothing, relaxed siting positions;

ii. Further research can be conducted to study how the learners control their classroom windows to regulate the internal temperature;

iii. Further research can be conducted on the variation of temperature in naturally ventilated classrooms;

iv. Further research can be conducted on the impact of overcrowding and classroom desk layout on thermal comfort in naturally ventilated classrooms;

v. Further research can be conducted on the impact of thermal comfort on the learners' learning outcome;

vi. Further research can be conducted on the impact thermal comfort on the health, wellness and productivity of learners.

8.2.2 Recommendations for the Department of Basic Education

The following recommendations are made to the Department of Basic Education:

i. The LTCP can be developed further into the Department of Basic Education (DBE) school classroom user's manual, to enable learners to manage their indoor thermal conditions;

ii. The LTCP can be developed further for the DBE school inspectors to inspect classrooms' health and safety compliance;

iii. The LTCP can be developed further as a teaching tool on indoor environmental factors. The learners and the teachers can be empowered about operating buildings for the achievement of comfortable and conducive learning environments.

8.3 Summary of research contributions

This research has contributed to the body of knowledge in thermal comfort in South African classrooms. It has developed age appropriate tools for the assessment of environments occupied by children in the South African school context.

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10 Addenda A

10.1 Ethics approval

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Reference number: EBIT/39/2014

26 August 2014

Ms LL Motsatsi
PO Box 395
Pretoria
0001

Dear Ms Motsatsi,

FACULTY COMMITTEE FOR RESEARCH ETHICS AND INTEGRITY

Your recent application to the EBIT Ethics Committee refers.

1 I hereby wish to inform you that the research project titled "Thermal comfort study of primary schools in Mamelodi township" has been approved by the Committee.

This approval does not imply that the researcher, student or lecturer is relieved of any accountability in terms of the Codes of Research Ethics of the University of Pretoria, if action is taken beyond the approved proposal.

2 According to the regulations, any relevant problem arising from the study or research methodology as well as any amendments or changes, must be brought to the attention of any member of the Faculty Committee who will deal with the matter.

3 The Committee must be notified on completion of the project.

The Committee wishes you every success with the research project.

Prof JJ Hanekom
Chair: Faculty Committee for Research Ethics and Integrity
FACULTY OF ENGINEERING, BUILT ENVIRONMENT AND INFORMATION TECHNOLOGY

10.2 Letter requesting permission to collect data from Head of school

Date

The Principal
School address
XXXX

Attention: Mr/Ms

Dear Sir / Madam,

REQUEST FOR PERMISSION TO COLLECT DATA ON THE THERMAL AND LIGHTING CONDITIONS IN CLASSROOMS AT ___________________________ SCHOOL

I am a _____________________researcher from ___________________. I need to collect data on temperature and lighting conditions in South African primary and secondary schools classrooms for _____________________.

The purpose of this letter is to request your permission to include your school in the sample of schools from which I will collect the following data:

- The perceptions of classroom users (teachers and learners) on the indoor environmental conditions in the classrooms. This data will be collected by means of questionnaires which should preferably be completed after the last lesson on a Friday to avoid disruption of teaching and learning. The completion and explanation of the questionnaire should take a maximum of 30 minutes.
- The thermal conditions and lighting levels in classrooms. Measuring instruments will be placed in selected classrooms to collect this data.

Although South African schools in general will benefit from the research findings, your school and the other schools which participate in the research study will reap direct benefits as each school will receive feedback as to what actions can be taken to optimise environmental comfort conditions in the existing classrooms.

I will follow up on the schools response to this request by telephone, e-mail or post within a week of the date of this letter to confirm whether I can conduct the abovementioned research at your school. One copy of each of the following documents is herewith attached for your information:

1. The questionnaire that will be used to collect data from learners and teachers;
2. The research protocol;
3. The consent and assent forms to be used in the research process; and
4. The letters of research approval from the Department of Basic Education (DBE).

Please do not hesitate to contact me on my direct line which is ___________________________ or through my e-mail address which is______________________ should you need any additional background information. I look forward to hearing from you.

Yours sincerely

10.3 **Letters of consent**

Date

Parental Permission for Participation of a Learner in a Research Study

Dear Parent or Guardian,

Your child has been invited to participate in a research study conducted by ________________________ from _____________________________. The purpose of this research is to assess the environmental conditions in classrooms, such as temperature, lighting levels and air flow.

Your child's participation will involve completing a questionnaire on how comfortable they feel in the classroom and if classroom conditions are comfortable enough for them in which to do their school work.

It is estimated that it will take 30 minutes to complete the form and that will be undertaken at a time that suits the teacher.

There are no risks or discomforts associated with this research. You child will benefit from learning about their classroom environment and how they can improve it for their learning comfort.

No names will be used in filling out the study's forms so all responses will be anonymous. No one at the school will have access to any of the information collected. Surveys will be kept in a locked filing cabinet which is accessible only to the researcher.

Participation in the study is entirely voluntary and there will be no penalty for not participating. All learners for whom we have parent consent will be asked if they wish to participate and only those who agree will complete the forms. Moreover, participants will be free to stop taking part in the study at any time.

Should you have any questions about the study please contact _____________________ at ________________.

Please give your permission by signing the enclosed consent form and by having your child return it to his or her register teacher tomorrow. Please keep this letter for your records.

Sincerely,

____

Consent to Participate

I have read the attached informed consent letter and agree that my child/children are allowed to participate in the research.

Learner's Name

Parent's or Guardian's Name (please print) Date

Classroom indoor environment quality study

Assent form

My name is ________________________________ from ____________________________.

I am asking you to take part in a research study because I am trying to learn more about the students comfort in classrooms. I want to learn about how kids your age feel about your classroom and if your classroom is OK for you to do your work in.

If you agree, you will be asked to complete a survey and you will be asked:

- how you feel about the temperature levels in your class;
- if you can see what your teacher has written on the board from where you are seated;
- if you can hear your teacher from where you are seated and;
- if you have enough space to work on.

Answering these questions will take about 30 minutes. You do not have to put your name on the survey.

Your parents or guardian have to say it's OK for you to be in the study. After they decide, you get to choose if you want to do it too. You do not have do this study. No one will be upset at you if you decide not to do this study. Even if you start, you can stop later if you want. You may ask questions about the study.

If you decide to be in the study I will not tell anyone else what you say or do in the study, even if your parents or teachers ask.

Signing the form below means that you have read this form or I have read it to you and that you are willing to be in this study.

____

Student's Name   Date

____

Parent's or Guardian's Name (please print)   Date

10.4 School building data form

School Building Data Form

General school information					
School name					
School building name		Classrooms			
School District					
School category					
School type	Public		private		independent
School contact					
School tel.					
Contact Title					
Contact Email					
School address					
Postal address					
City					
Total number of occupants	Learners		Teachers		
Timetable/day plan	Yes		No		
Building occupancy					
Year of building occupation					
Year of the most recent renovation? Explain					
Grades occupying building					
Occupancy per grade	Grade	Grade	Grade	Grade	Grade
How many weeks are the classrooms occupied?					
How long are the classrooms occupied on an average day?	Grade	Grade	Grade	Grade	Grade
General building information					
Year of building occupation					
Year of the most recent renovation? What?					
School building configuration					
Building location					
Building orientation					
Building Shading	internal		external		
Classroom location(check plan i.e block)	Grade	Grade	Grade	Grade	Grade
Building orientation(N/S/E/W)	Grade	Grade	Grade	Grade	Grade
Building characteristics					
Building material					
Surface colour	internal		external		
Façade					
Outdoor designs considerations					

Indoor designs considerations											
Internal heat gain											
Areas											
Surface area(2(lxbxw))		Grade		Grade		Grade		Grade		Grade	
Area(lxb)		Grade		Grade		Grade		Grade		Grade	
Fenestration area		Grade		Grade		Grade		Grade		Grade	
Door(type)		C	O	C	O	C	O	C	O	C	O
Window(type)		C	O	C	O	C	O	C	O	C	O
Other											
Do the classrooms have air conditioning? Y/N		Grade		Grade		Grade		Grade		Grade	
Flooring											
		Grade		Grade		Grade		Grade		Grade	
Material											
Condition											
Other											
Energy consumption											
Energy usage data for school											
Drawings Availability											

10.5 **Field work protocol**

Objective

The objective of the field work is to collect quantitative data using the questionnaires from occupants (learners and teacher) and data loggers use to record thermal temperature.

Data collection

- ***Quantitative data 1***

The appropriate questionnaires will be distributed to students who have given consent to participate in the research by the teacher or researcher.

The completion of questionnaires is dependent on the on the teachers' schedule and availability. Ideally the questionnaires will only be completed 30 minutes before the end on the day, once, at the end of the week, when students and teacher are available to do so.

The researcher will be present to map out the classroom layout and approximate positions of students taking survey, i.e. close to window or middle of class.

The researcher will explain to the learners the objectives of the study and how to complete the questionnaires.

Typical classroom plan that will be used for the location of data logger and mapping of furniture (desks/table/chairs/boards) and furniture use (learner seating). (See Figure 47 below)

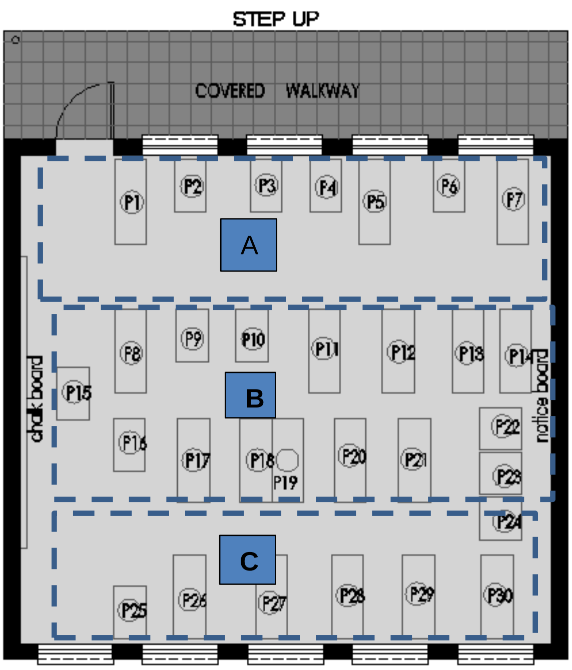


Figure 47: Mapping of location of learner

- ***Quantitative data 2***

The instruments that will be used to collect the quantitative data will be HOBO pendant Temp/Light data loggers, which are electronic devices that that will record indoor temperature and light levels data over time with the built-in sensors. The data loggers are small, battery powered, portable, and equipped with a microprocessor, internal memory for data storage.

The data loggers will be programmed to automatically and left unattended to collect data at the same time for the duration of study. This will allow for a comprehensive, accurate picture of the environmental conditions being monitored.

  - ***Data logger positioning***

1. The data will be recorded 600mm from the internal (midpoint & corner)wall and at the centre of the classroom.(See figure 48)
2. The data logger is to be fixed on the centre front edge of the occupied desk, to avoid disturbing learner.
3. To measure the vertical air temperature difference , two data loggers will be hung +-600mm (head area when seated) and +/-100mm(ankle area) from the finished floor level

Data from loggers will be collected at the end of the day and placed in the same position the following day for the duration of study.

- ***It would be ideal if the students participated in the research or used findings from research to learn about the thermal conditions in their classroom, so that the data logger is closely monitored.***

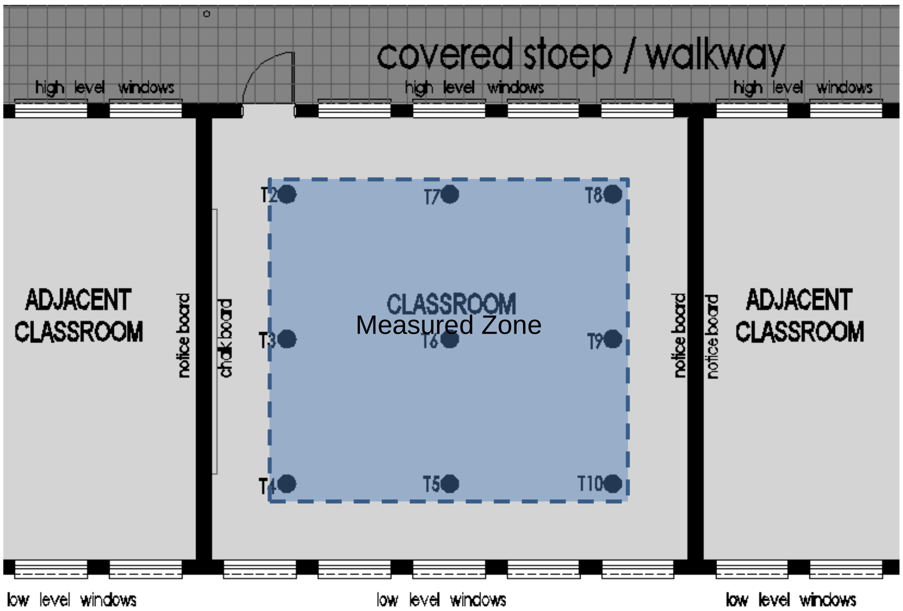


Figure 48: Location of data loggers

Typical classroom section drawing that will be used for the analysing structure and understanding building specification (See figure 49).

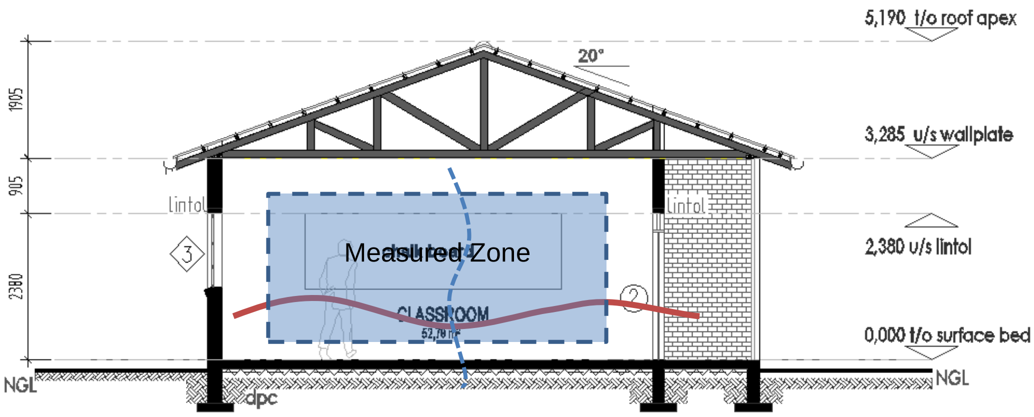


Figure 49 Section of school

10.6 Data collection instrument for quantitative data: Questionnaires

<u>Learner Survey: Environmental Factors (Grade 3-5)</u>

Date:		Time:	
Room number / location		Desk ref:	

I am a …

GIRL 		 BOY	

My classroom is clean and neat!

I strongly agree / 2	I agree / 1	It is Ok /0	I disagree /-1	I strongly disagree /-2
				

The light on my desk is <u>bright</u> enough for reading and writing?

I strongly agree / 2	I agree / 1	It is Ok /0	I disagree /-1	I strongly disagree /-2
				

I can SEE the board very well from my desk!

I strongly agree / 2	I agree / 1	It is Ok /0	I disagree /-1	I strongly disagree /-2
				

My classroom is HOT!!

I strongly agree / 2	I agree / 1	It is Ok /0	I disagree /-1	I strongly disagree /-2
				

My classroom is COLD!

I strongly agree / 2	I agree / 1	It is Ok /0	I disagree /-1	I strongly disagree /-2
				

My classroom has a lot of FRESH AIR!

I strongly agree / 2	I agree / 1	It is Ok /0	I disagree /-1	I strongly disagree /-2
				

I have enough SPACE to do my work!

I strongly agree / 2	I agree / 1	It is Ok /0	I disagree /-1	I strongly disagree /-2
				

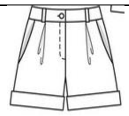
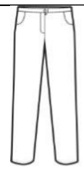
I can HEAR my teacher from my desk!

I strongly agree / 2	I agree / 1	It is Ok /0	I disagree /-1	I strongly disagree /-2
				

I sit and write COMFORTABLY!

I strongly agree / 2	I agree / 1	It is Ok /0	I disagree /-1	I strongly disagree /-2
				

I am WEARING …

							Other
							

Faculty of Engineering, Built Environment and Information Technology

Student Questionnaires: Environmental Factors (grade 6- 7)

Date:		Time:	
Room number / location		Seat ref:	

Please complete the survey below:

Age		Girl		Boy	

Are you satisfied with the quality of LIGHT in your classroom for learning?

Very satisfied/ +1	Satisfied / 1	Ok/0	Not satisfied but accepted /-1	Not satisfied ,not acceptable/-2

Are you satisfied with the VISIBILITY your teachers' writing on the board?

Very satisfied/ +1	Satisfied / 1	Ok/0	Not satisfied but accepted /-1	Not satisfied ,not acceptable/-2

Are you satisfied with the surrounding TEMPERATURE at your desk?

Very satisfied/ +1	Satisfied / 1	Ok/0	Not satisfied but accepted /-1	Not satisfied ,not acceptable/-2

Are you satisfied with the levels of ventilation / fresh air for the work you are doing?

Very satisfied/ +1	Satisfied / 1	Ok/0	Not satisfied but accepted /-1	Not satisfied ,not acceptable/-2

Are you satisfied with the amount of space you have for the work you are doing?

Very satisfied/ +1	Satisfied / 1	Ok/0	Not satisfied but accepted /-1	Not satisfied ,not acceptable/-2

How well can you hear the teacher from your desk?

Very well/ +1	Well enough/ 1	Ok/0	Not very well/-1	I can't hear/-2

Are you satisfied with the comfort of your chair and desk for the work you are doing?

Very satisfied/ +1	Satisfied / 1	Ok/0	Not satisfied but accepted /-1	Not satisfied ,not acceptable/-2

Indicate which FACTOR do you think contributes the MOST to a good learning environment in the classroom - Using a rating of 1-5, with 5 as the highest and 1 the lowest

FACTOR	Good lighting at desk	Good visibility of board	Comfortable temperatures	Better ventilation	More space	Less noise from outside	More comfortable furniture
Other							

Indicate which FACTOR do you think AFFECTS your academic results the MOST - Using a rating of 1-5, with 5 as the highest and 1 the lowest

Factor	Poor classroom environment	Not enough learning materials	Not enough time in classrooms	Not enough space for doing work	Problems at home	Hunger / health
Other						

Indicate which FACTOR do you think contributes the MOST to the improvement your academic results - Using a rating of 1-5, with 5 as the highest and 1 the lowest

FACTOR	More time with educators	Access to reading / learning material	Access to computers and the internet	More comfortable learning space in school	A safe and comfortable place to do learn out of class	Provision of food at school
Other						

Comments:

Educator Survey: Environmental Factors

Date:		Time:	
Room number / location		Seat ref:	

Please complete the survey below:

Age	
Gender	Male / Female

What measure would best describe the quality of light on your classroom for teaching?

Very good/2	Good/1	Adequate/0	Inadequate/-1	Poor/-2

What measure would best describe the visibility your writing of the board for your learners?

Very good/2	Good/1	Adequate/0	Inadequate/-1	Poor/-2

What measure would best describe your surrounding temperature for the work you are doing?

Very good/2	Good/1	Adequate/0	Inadequate/-1	Poor/-2

What measure would best describe levels of ventilation / fresh air for the work you are doing?

Very good/2	Good/1	Adequate/0	Inadequate/-1	Poor/-2

What measure would best describe the amount of space you have for the work you are doing?

Very good/2	Good/1	Adequate/0	Inadequate/-1	Poor/-2

What measure would best describe the levels of noise for the work you are doing?

Very good/2	Good/1	Adequate/0	Inadequate/-1	Poor/-2

What measure would best describe the comfort of your chair and desk for the work you are doing?

Very good/2	Good/1	Adequate/0	Inadequate/-1	Poor/-2

Indicate which of the following would contribute most to a better learning environment in the classroom (Using a rating of 1-5, with 5 as the highest and 1 the lowest)

Factor	Better lighting at desk	Better visibility of board	More comfortable temperatures	Better ventilation	More space	Less noise	More comfortable furniture
Rating							
Other							

Rate the following factors that may impede the most on learners' achievements (Using a rating of 1-5, with 5 as the highest and 1 the lowest)

Factor	Poor classroom environment	Not enough learning materials	Not enough time in classrooms	No space to work out of school time	Problems at home	Hunger / health	Learning difficulties
Rating							
Other							

Indicate which of the following would contribute most to learners achieving better educational results. Using a rating of 1-5, with 5 as the highest and 1 the lowest)

Factor	More time with educators	Better access to reading / learning material	Better access to computers and the internet	More comfortable learning space in school	A safe and comfortable place to do learn out of class	Provision of food at school
Rating						
Other						

Comments:

10.7 Data collection instrument for quantitative data: HOBO Pendant Data logger

onset®

HOBO Pendant® Temperature/Light Data Logger 8K - UA-002-08

Measures:

Temperature, Light Intensity, Water Temp

Contact Onset at 1-800-564-4377

Features:

Description:

This HOBO Pendant® logger is a miniature, waterproof two-channel temperature and relative light level data logger. The 8K model comes at a great value and is suitable for indoor, outdoor, and underwater applications. This logger holds approximately 6.5K of 10-bit readings. Use a solar radiation shield for accurate temperature measurement in sunlight.See RS1 Solar Radiation Shield (assembly required) and M-RSA (pre-assembled) Solar Radiation Shield. Note that using a solar radition shield prevents the use of the light sensor.

Optical Interface for data transfer - click to zoom

- Low-cost temperature with alarm indication or light intensity
- Waterproof housing for wet or underwater use
- Data readout in less than 30 seconds via fast Optic USB interface

Detailed Specifications:

Measurement range
Temperature: -20° to 70°C (-4° to 158°F)
Light: 0 to 320,000 lux (0 to 30,000 lumens/ft^2)

Accuracy:
Temperature: ± 0.53°C from 0° to 50°C (± 0.95°F from 32° to 122°F), see Plot A
Light intensity: Designed for measurement of relative light levels, see Plot D for light wavelength response

Resolution:
Temperature: 0.14°C at 25°C (0.25°F at 77°F), see Plot A

Drift: Less than 0.1°C/year (0.2°F/year)

Response time:
Airflow of 2 m/s (4.4 mph): 10 minutes, typical to 90%
Water: 5 minutes, typical to 90%

Time accuracy: ± 1 minute per month at 25°C (77°F), see Plot B

Operating range
In water/ice: -20° to 50°C (-4° to 122°F)
In air: -20° to 70°C (-4° to 158°F)

Water depth rating: 30 m from -20° to 20°C (100 ft from -4° to 68°F), see Plot C

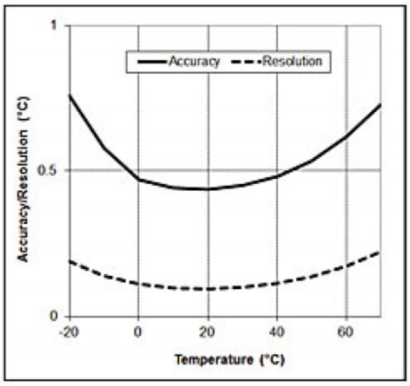
NIST traceable certification: Available for temperature only at additional charge; temperature
range -20° to 70°C (-4° to 158°F)

Battery life: 1 year typical use

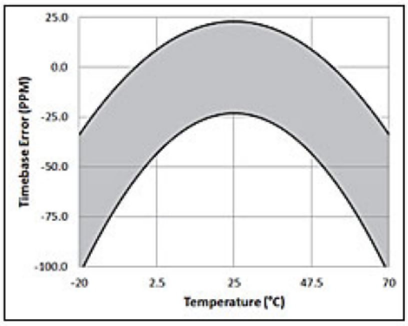
Memory
UA-002-08: 8K bytes (approximately 3.5K combined temperature and light readings or events)
UA-002-64: 64K bytes (approximately 28K combined temperature and light readings or events)

Materials: Polypropylene case; stainless steel screws; Buna-N o-ring

Weight: 18 g (0.6 oz)



Plot A



Plot B

11 Addenda B – Collected Data

11.1 Case Study A: Botlhabatsatsi

11.1.1 Case Study A: Botlhabatsatsi Primary Grade 3

Table 72: Actual temperature at desk (T1-T9) on 9/09/2013

09-Sep-13	Min Temp	Max Temp
T1	17.9	29.45
T2	17.8	29.4
T3	19.18	29.7
T4	18.5	30.4
T5	18.5	29.9
T6	20.04	30.15
T7	20.9	36.07
T8	19.09	31.6
T9	17.85	29.45
Average	**18.86**	**30.68**

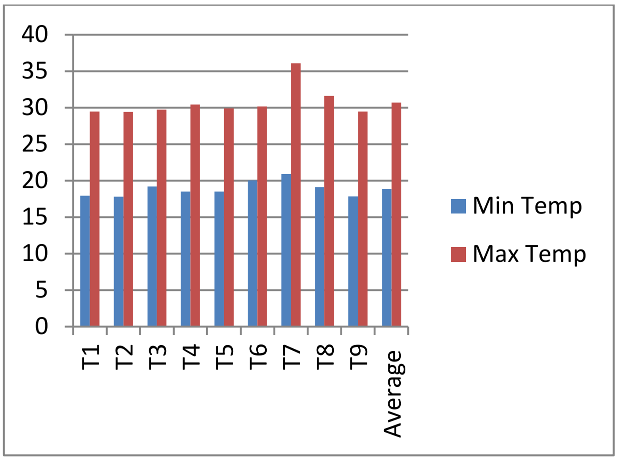


Table 72 show temperatures taken in the grade 3 classroom on 9 September 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) in the classroom is 17.8°C and is recorded at T2 postioned close windows. The maximum temperature (taken in the afternoon - 14:00) in the classroom is 36.1°C recorded at T7 positioned closed to door. The minimum and maximum temperatures at desks for 9 September 2013 range from 17.8°C to 36.1°C between 08:00 and 14:00.

T1 – T3 : minimum and maximum temperature range from 17.8°C (08:00)to 29.7°C (14:00)

T4 – T6 : minimum and maximum temperature range from 15.8°C (08:00)to 30.4°C (14:00)

T7 – T9: minimum and maximum temperature range from 17.9°C (08:00)to 36.1°C (14:00)

The average for minimum and maximum temperatures at desks for 9 September 2013 range from 18.9°C to 30.7°C between 08:00 and 14:00.

Table 73: Actual temperature at desk (T1-T9) on 10/09/2013

10-Sep-14	Min Temp.	Max Temp
T1	22.6	42.64
T2	22.9	44.09
T3	25.13	37.49
T4	22.6	29.95
T5	21.18	30.05
T6	21.38	30.46
T7	26.78	30.05
T8	20.52	29.35
T9	21.18	29.95
T10	21.28	29.55
Average	**22.555**	**33.358**

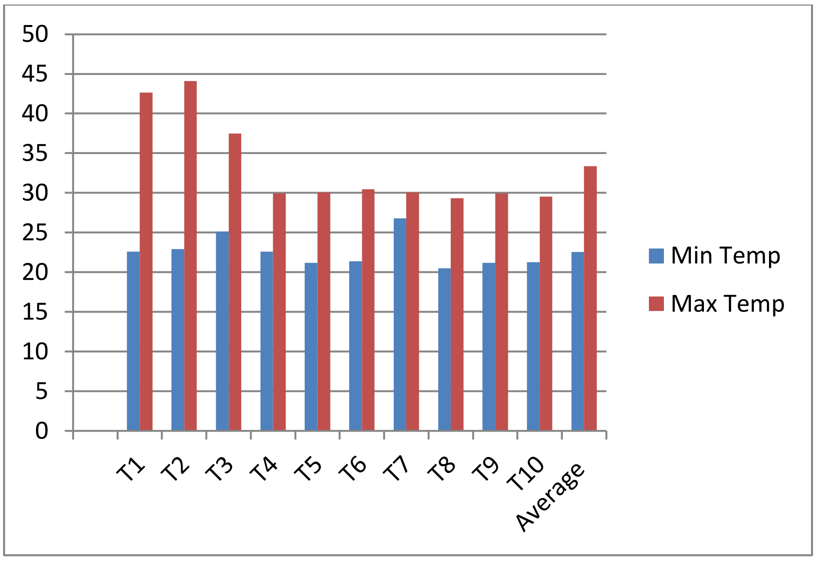


Table 73 show temperatures taken in the grade 3 classroom on 10 September 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) in the classroom is 20.5°C and is recorded at T8 postioned below windows. The maximum temperature (taken in the afternoon - 14:00) in the classroom is 44.1°C recorded at T2 positioned closed to window. The minimum and maximum temperatures at desks for 10 September 2013 range from 20.5°C to 44.1°C between 08:00 and 14:00.

T1 – T3 : minimum and maximum temperature range from 22.6°C (08:00)to 44.1°C (14:00)

T4 – T6 : minimum and maximum temperature range from 21.2°C (08:00)to 30.5°C (14:00)

T7 – T9: minimum and maximum temperature range from 20.5°C (08:00)to 29.9°C (14:00)

The average for minimum and maximum temperatures for 10 September 2013 ranges from 22.6°C to 33.4°C between 08:00 and 14:00.

Table 74 Actual temperature at desk (T1-T9) on 11/09/2013

11/09/2013	Min temp	Max temp
T1	22.6	35.6
T2	25.32	36.8
T3	22.32	40.18
T4	22.6	30.56
T5	21.09	29.55
T6	21.19	30.56
T7	20.14	29.15
T8	20.99	29.7
T9	20.8	29.35
T10	21.38	29.8
Average	**21.843**	**32.125**

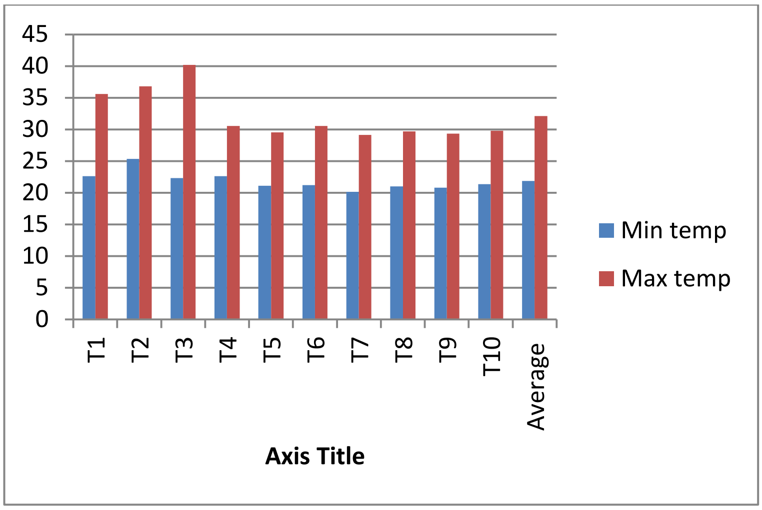


Table 74 show temperatures taken in the grade 3 classroom on 11 September 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) in the classroom is 20.1°C and is recorded at T7 postioned close high windows. The maximum temperature (taken in the afternoon - 14:00) in the classroom is 40.2°C recorded at T3 positioned closed to window The minimum and maximum temperatures at desks for 11 September 2013 range from 20.1°C to 40.2°C between 08:00 and 14:00.

T1 – T3 : minimum and maximum temperature range from 22.3°C (08:00) to 40.2°C (14:00)

T4 – T6 : minimum and maximum temperature range from 21.1°C (08:00) to 30.6°C (14:00)

T7 – T9: minimum and maximum temperature range from 20.8°C (08:00) to 29.8°C (14:00)

The average for minimum and maximum temperatures for 11 September 2013 range from 21.8°C to 32.1°C between 08:00 and 14:00.

Table 75 Actual temperature at desk (T1-T9) on 12/09/2013

12/09/2013	Min temp	Max temp
T1	22.2	35.97
T2	23.9	35.97
T3	22.2	35.86
T4	22.12	29.45
T5	24.5	30.15
T6	22	29
T7	22.1	29.25
T8	22.1	27.45
T9	22.1	29.45
T10	22.1	29.45
T11	22.5	29.65
Average	**22.5**	**31.2**

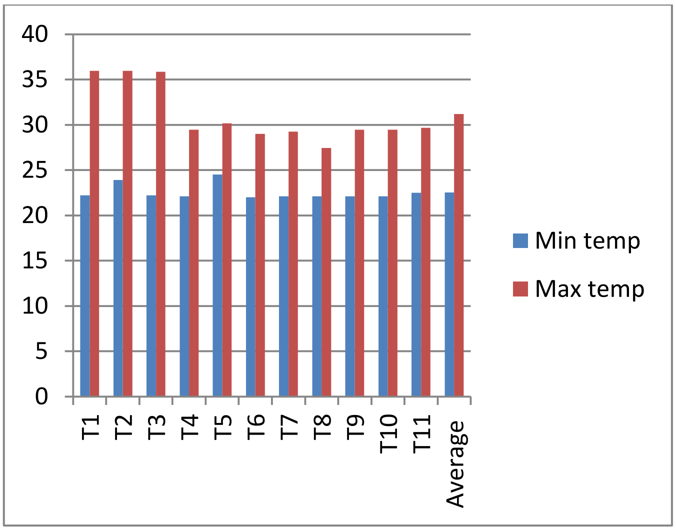


Table 75 show temperatures taken in the grade 3 classroom on the 12 September 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) in the classroom is 22°C and is recorded at T6 postioned at the back of classroom. The maximum temperature (taken in the afternoon - 14:00) in the classroom is 35.9°C recorded at T1/T2/T3 positioned closed to window and door. The minimum and maximum temperatures at desks for 11 September 2013 range from 20.1°C to 40.2°C between 08:00 and 14:00.

T1 – T3 : minimum and maximum temperature range from 22.2°C (08:00) to 35.97°C (14:00)

T4 – T6 : minimum and maximum temperature range from 22°C (08:00) to 30.2°C (14:00)

T7 – T9: minimum and maximum temperature range from 22.1°C (08:00) to 29.5°C (14:00)

The average for minimum and maximum temperatures for 12 September 2013 range from 22.5°C to 31.2°C between 08:00 and 14:00.

Table 76 Actual temperature at desk (T1-T9) on 13/09/2013

13/09/2013	Min temp	Max temp
T1	23.5	32.8
T2	22.7	31.8
T3	25.7	33.6
T4	21.9	30.9
T5	21.5	30.9
T6	21.4	30.55
T7	21.3	31.1
T8	21.2	30.6
T9	21.1	31.6
T10	20.9	31.3
CENTRE	20.6	30.9
Average	**22.12**	**31.515**

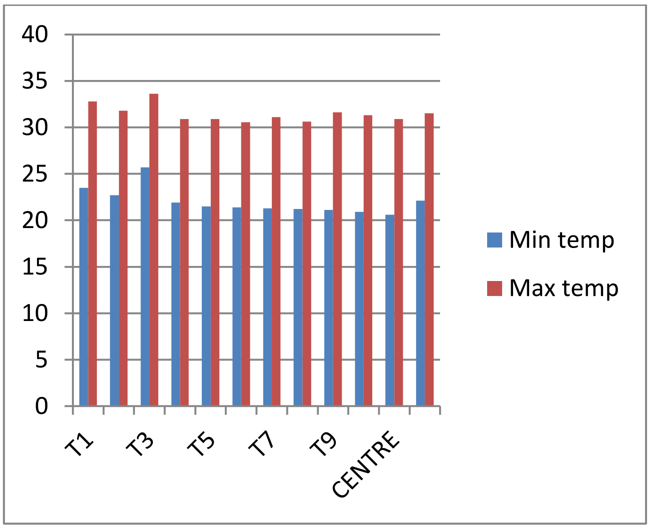


Table 76 show temperatures taken in the grade 3 classroom on 13 September 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) in the classroom is 20.9°C recorded at T9 (Teacher's Desk) postioned at the back corner of class. The maximum temperature (taken in the afternoon - 14:00) in the classroom is 33.6°C and is recorded at T3 positioned at the back of the class near to windows.

T1 – T3 : minimum and maximum temperature range from 22.7°C (08:00) to 33.6°C (14:00)

T4 – T6 : minimum and maximum temperature range from 21.3°C (08:00) to 31.1°C (14:00)

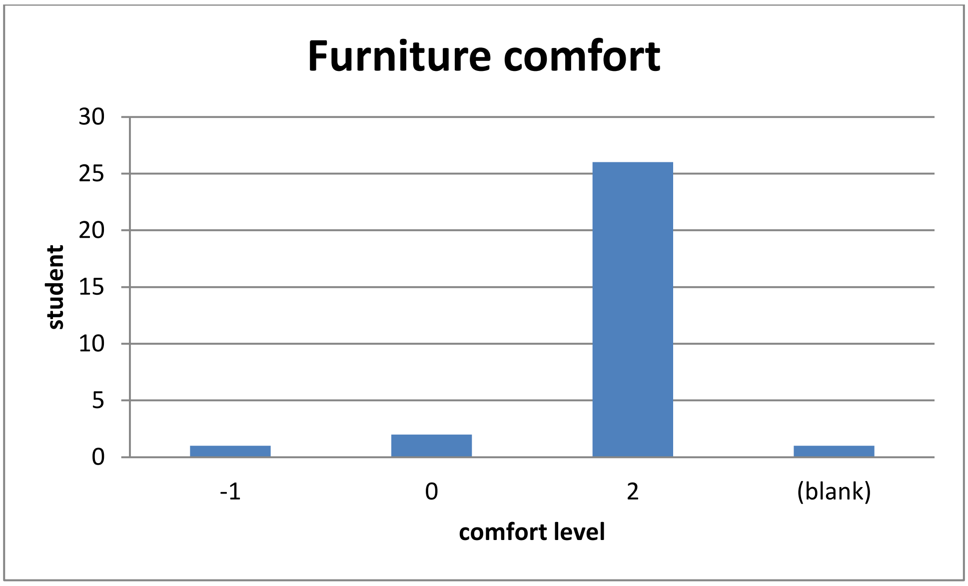
T7 – T9: minimum and maximum temperature range from 21.1°C (08:00) to 31.1°C (14:00)

The average for minimum and maximum temperatures for 12 September 2013 range from 22.1°C to 31.5°C between 08:00 and 14:00.

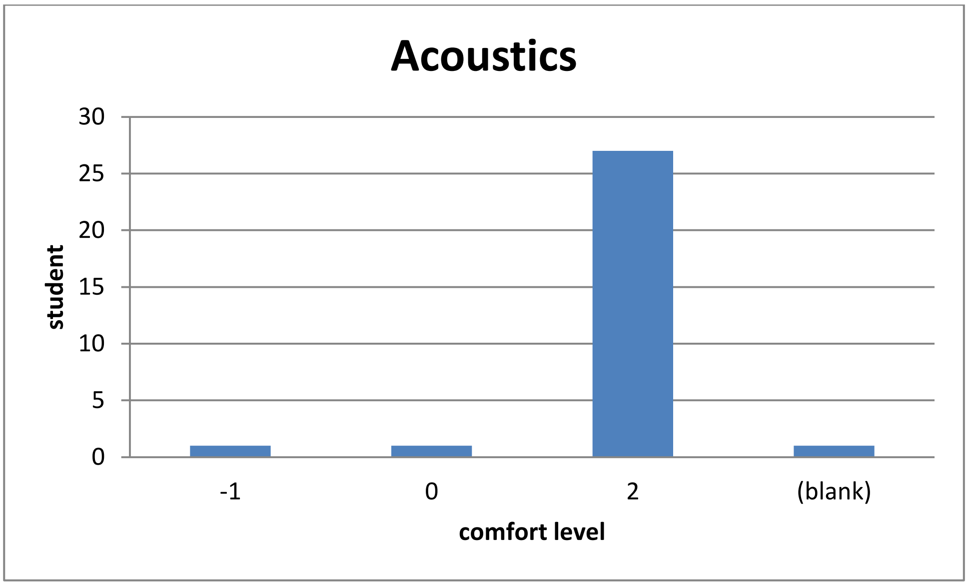
Case study A: Grade 3 perceptions of indoor environment

BOTLABATSATSI PRIMARY SCHOOL STATISTICS
2013

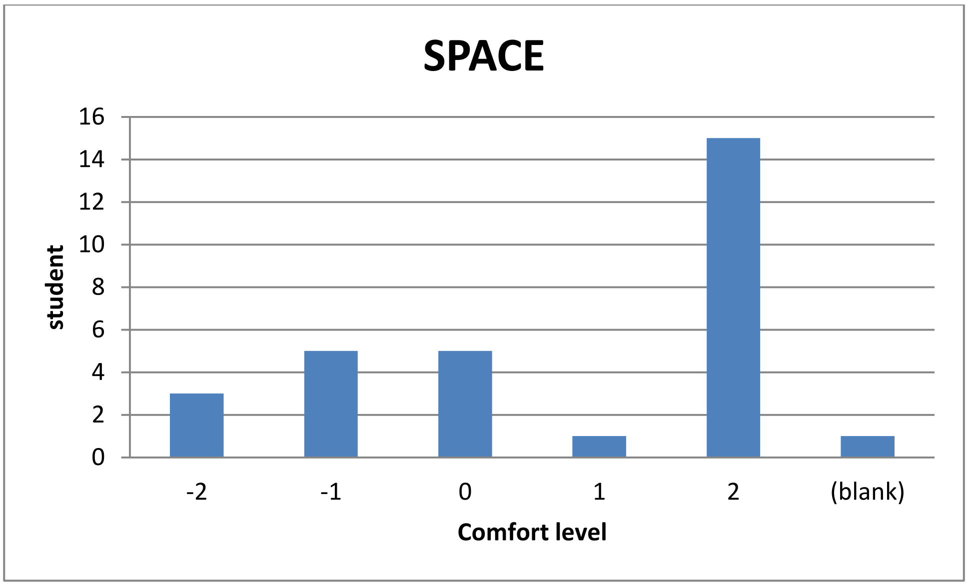
GRADE	**BOYS**	**GIRLS**	**TOTAL**	**EDUCATOR**
GRADE R	13	15	28	DIKGALE N
GRADE 1	12	16	28	RANKAPOLE P
GRADE 2	25	17	42	LETSOALO KT
GRADE 3	17	14	31	**KGOADI R**
GRADE 4	20	9	29	MASEMOLA VK
GRADE 5	14	17	31	**MOLOBI MC**
GRADE 6	13	15	28	**KEKANA LFD**
GRADE 7	24	13	37	**APHANE P**
TOTAL	138	116	254	
TOTAL (1-7)	125	101	226	
GRADE RR	11 BOYS	9 GIRLS	20	KOPANE BR
Total Learners	**149**	**125**	**274**	



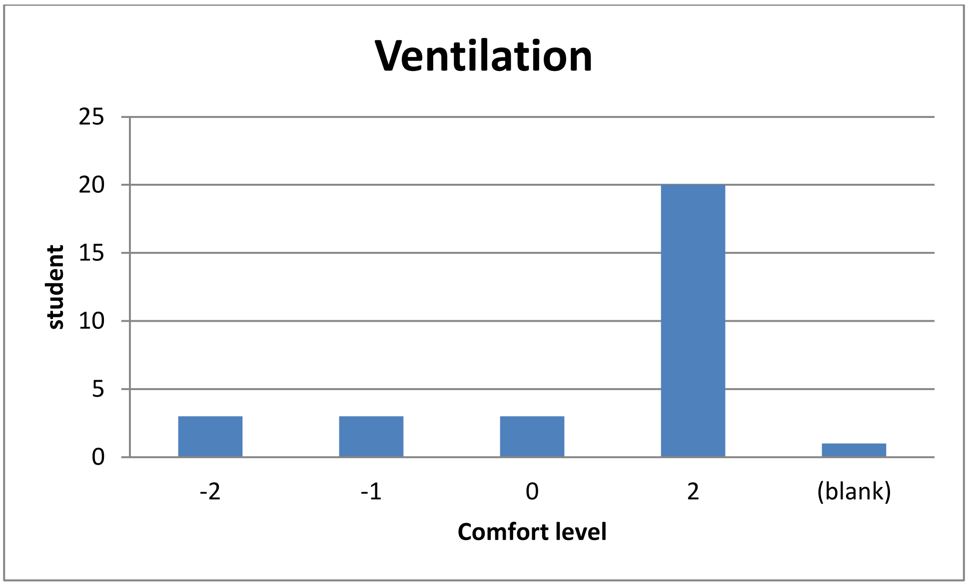
Majority of the learners were comfortable in their desks and chair.



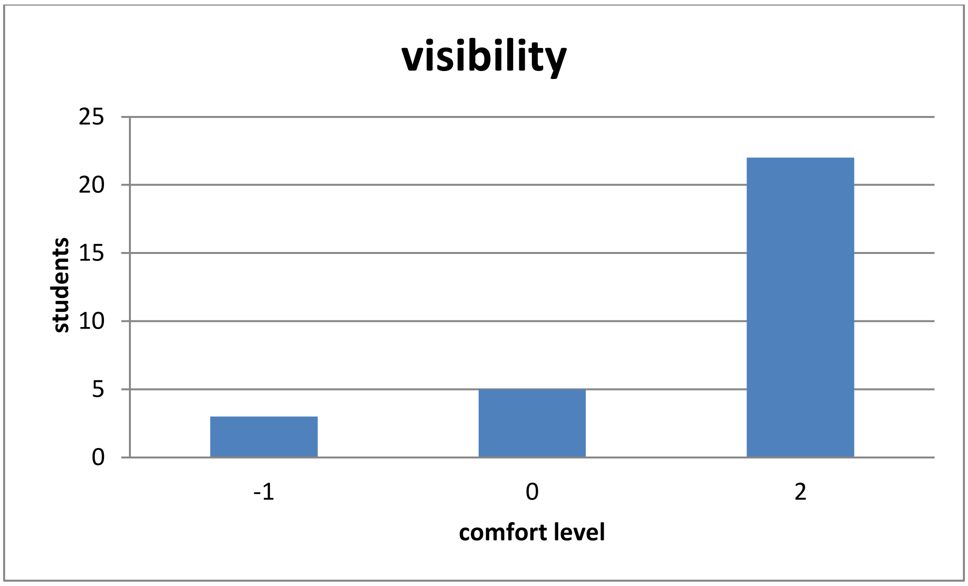
Majority of the learners could hear the teacher from their desks.



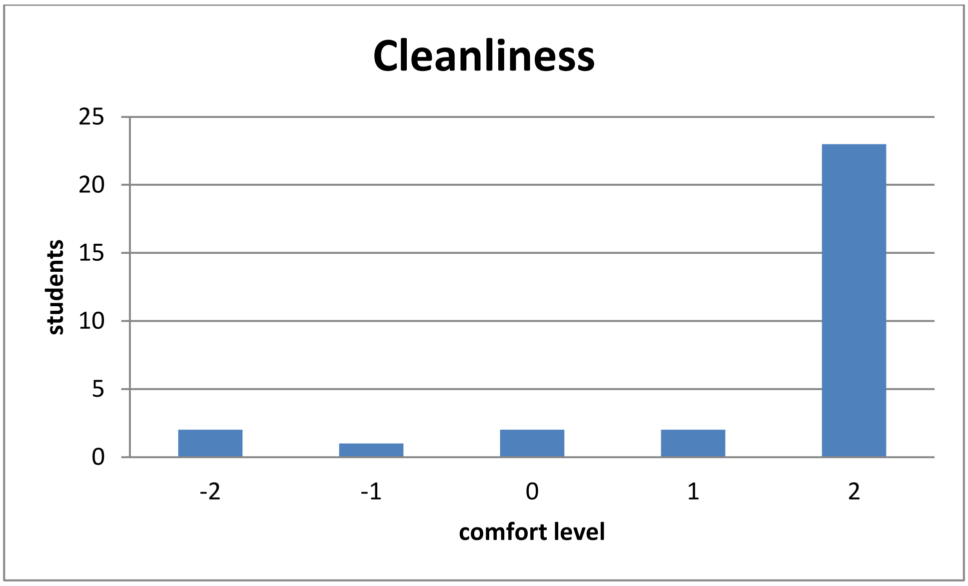
Majority of the learners had enough space for working.



Majority of the learners felt that there was enough fresh air flowing in the classroom.



Majority of the learners agreed that they could see what the teacher has written on the board very well.



Majority of the learners agreed that their classroom was clean.

11.1.2 **Case Study A: Botlhabatsatsi Primary Grade 5**

Table 77 Actual temperature at desk (T1-T10 & Centre) on 09/102013

09/09/2013	Min temp	Max temp
T1	17.9	27.7
T2	17.8	28.2
T3	17.8	27.1
T4	17.8	27.1
T5	17.6	28.2
T6	17.9	27.4
T7	N/R	N/R
T8	17.9	27.9
T9	17.9	27.1
T10	N/R	N/R
Centre	17.7	24.6
Average	**17.81**	**27.59**

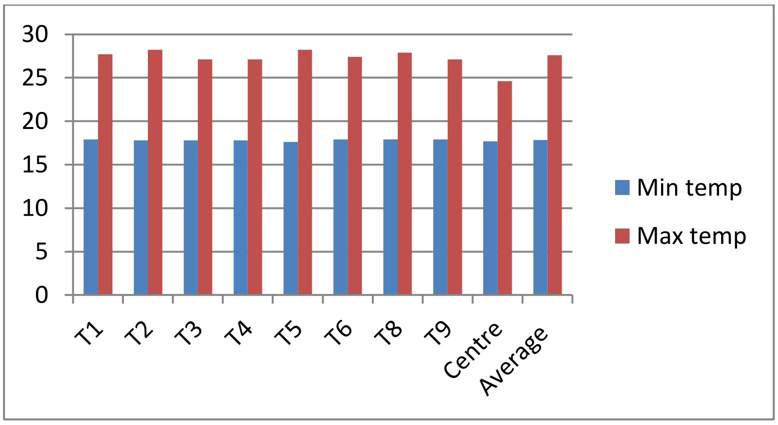


Table 77 show temperatures taken in the grade 5 classroom on 9 September 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) in the classroom is 17.6°C and is recorded at T5 postioned at the middle of class. The maximum temperature (taken in the afternoon - 14:00) in the classroom is 28.2°C and is recorded at T2/T5 positioned at the middle- back of class near to windows. The minimum and maximum temperatures for 9 September 2013 range from 17.6°C to 28.2°C between 08:00 and 14:00.

T1 – T3 : minimum and maximum temperature range from 17.8°C (08:00) to 28.2°C (14:00)

T4 – T6 : minimum and maximum temperature range from 17.6°C (08:00) to 28.2°C (14:00)

T8– T9: minimum and maximum temperature range from 17.9°C (08:00) to 27.1°C (14:00)(T7 – no readings)

The average for minimum and maximum temperatures for 9 September 2013 range from 17.8°C to 27.6°C between 08:00 and 14:00.

Table 78 Actual temperature at desk (T1-T10 & Centre) on 10/102013

10/09/2013	Min temp	Max temp
T1	20.6	28.7
T2	20.6	28.7
T3	21.1	28.7
T4	21.1	20.3
T5	20.8	27.9
T6	20.3	28.6
T7	20.8	28.4
T8	20.5	28.5
T9	20.6	29.7
T10	21.1	28.1
Centre	20.2	29.2
Average	**20.75**	**27.76**

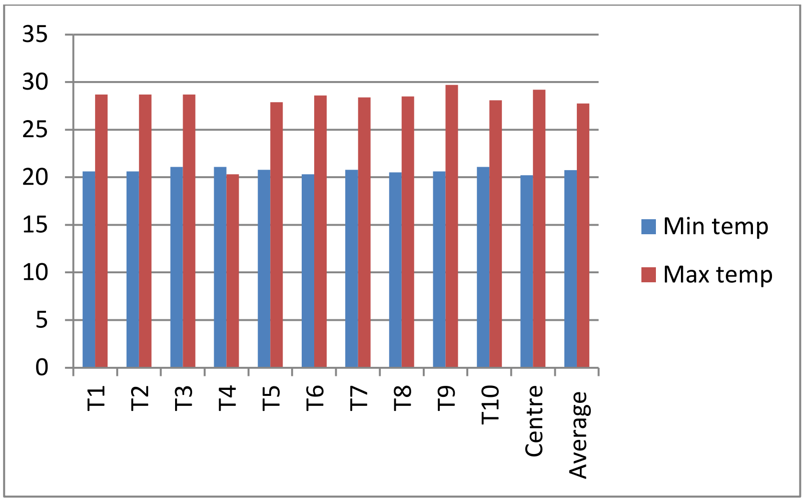


Table 78 show temperatures taken in the grade5 classroom on 10 September 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) in the classroom is 20.3°C and is recorded at T6 postioned at the front middle of class. The maximum temperature (taken in the afternoon - 14:00) in the classroom is 29.7°C and is recorded at T9 positioned at the back of class .

T1 – T3 : minimum and maximum temperature range from 20.6°C (08:00) to 28.7°C (14:00)

T4 – T6 : minimum and maximum temperature range from 20.3°C (08:00) to 28.6°C (14:00)

T7 – T9: minimum and maximum temperature range from 20.5°C (08:00) to 29.7°C (14:00)

The average for minimum and maximum temperatures for 10 September 2013 range from 20.8°C to 27.8°C between 08:00 and 14:00.

Table 79 Actual temperature at desk (T1-T10 & Centre) on 11/102013

11/09/2013	Min temp	Max temp
T1	20.1	28.7
T2	20.3	28.9
T3	20.3	28.6
T4	20.2	28.5
T5	20	29.1
T6	19.6	28.1
T7	19.9	28.8
T8	19.7	28.5
T9	20.3	28.9
T10	20.2	28.5
Centre	19.7	28.5
Average	**20.06**	**28.66**

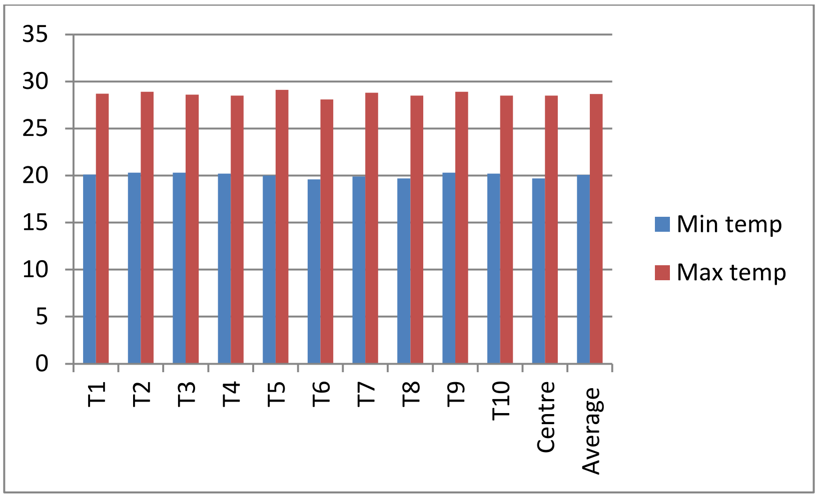


Table 79 show temperatures taken in the grade 5 classroom on 11 September 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) in the classroom is 20°C and is recorded at T6 postioned at the middle back of class. The maximum temperature (taken in the afternoon - 14:00) in the classroom is 29.1°C and is recorded at T5 positioned at the middle of class. The minimum and maximum temperatures for 11 September 2013 range from 20°C to 29.1°C between 08:00 and 14:00.

T1 – T3 : minimum and maximum temperature range from 20.1°C (08:00) to 28.9°C (14:00)

T4 – T6 : minimum and maximum temperature range from 19.6°C (08:00) to 28.1°C (14:00)

T7 – T9: minimum and maximum temperature range from 19.7°C (08:00) to 28.9°C (14:00)

The average for minimum and maximum temperatures for 10 September 2013 range from 20.1°C to 28.7°C between 08:00 and 14:00.

Table 80 Actual temperature at desk (T1-T10 & Centre) on 12/102013

12/09/2013	Min temp	Max temp
T1	20.7	27.7
T2	22	26.3
T3	21.7	26.1
T4	21.2	26.5
T5	21.4	26.4
T6	21.4	26.7
T7	21.8	26.3
T8	21.5	26.2
T9	21.2	26.4
T10	21.7	26.4
Centre	20.9	26.4
Average	**21.46**	**26.5**

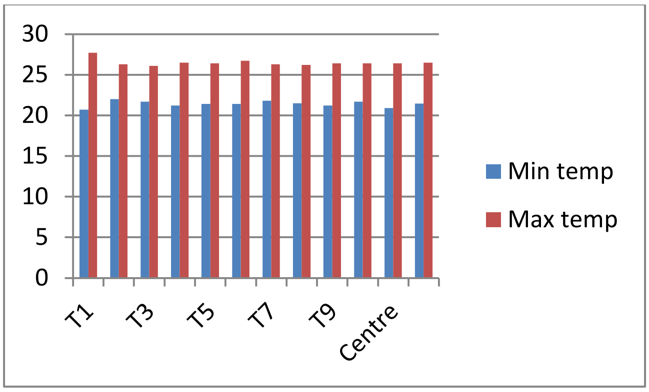


Table 80 show temperatures taken in the grade 5 classroom on 10 September 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) in the classroom is 20.7°C and is recorded at T1 postioned at the front corner of class next to door. The maximum temperature (taken in the afternoon - 14:00) in the classroom is 27.7°C and is recorded at T1 positioned at the front of class near to the door.

T1 – T3 : minimum and maximum temperature range from 20.7°C (08:00) to 27.7°C (14:00)

T4 – T6 : minimum and maximum temperature range from 21.2°C (08:00) to 26.5°C (14:00)

T7 – T9: minimum and maximum temperature range from 21.2°C (08:00) to 26.4°C (14:00)

The average for minimum and maximum temperatures for 12 September 2013 range from 21.5°C to 26.5°C between 08:00 and 14:00.

Table 81 Actual temperature at desk (T1-T10 & Centre) on 13/102013

13/09/2013	Min temp	Max temp
T1	20.8	29.6
T2	21.1	28.5
T3	21.2	28.4
T4	21.4	28.8
T5	21.4	29.5
T6	21.3	29.1
T7	N/R	N/R
T8	21.1	29.5
T9	21.8	29.2
T10	20.9	28.9
Average	**21.2**	**29.06**

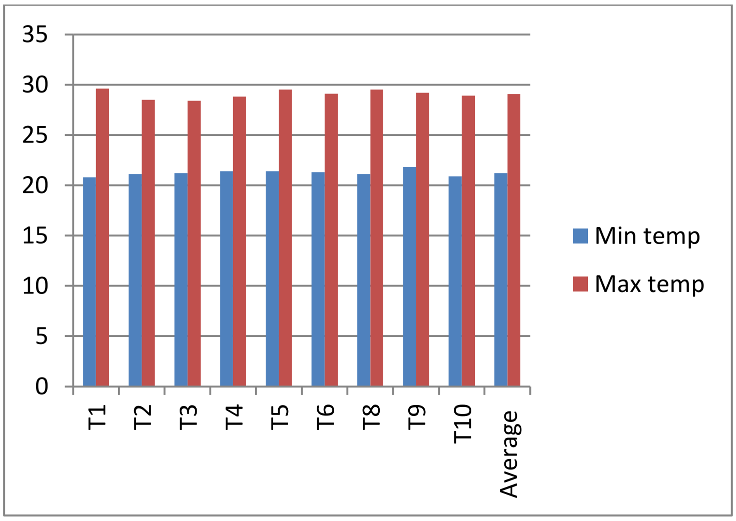


Table 81 show temperatures taken in the grade 5 classroom on 13 September 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) in the classroom is 20.8°C and is recorded at T1 postioned at the front of class. The maximum temperature (taken in the afternoon -

14:00) in the classroom is 29.6°C and is recorded at T1 positioned at the front of class near to the door.

T1 – T3 : minimum and maximum temperature range from 20.8°C (08:00) to 29.6°C (14:00)

T4 – T6 : minimum and maximum temperature range from 21.3°C (08:00) to 29.5°C (14:00)

T8 – T9: minimum and maximum temperature range from 21.1°C (08:00) to 29.5°C (14:00)(T7 no readings)

The average for minimum and maximum temperatures for 13 September 2013 range from 21.2°C to 29.06°C between 08:00 and 14:00.

11.1.3 **Case Study A: Botlhabatsatsi Primary: Grade 6**

Table 82 Actual temperature at desk (T1-T10 & Centre) on 09/09/2013

09/09/2013	Min temp	Max temp
T1	17.8	31.5
T2	18.7	27.6
T3	17.8	27.3
T4	17.8	27.9
T5	17.6	27.3
T6	17.6	27.2
T7	17.8	27.7
T8	17.8	27.7
T9	17.8	27.4
T10	17.9	22
CENTRE	17.8	31.5
Average	**17.86**	**27.36**

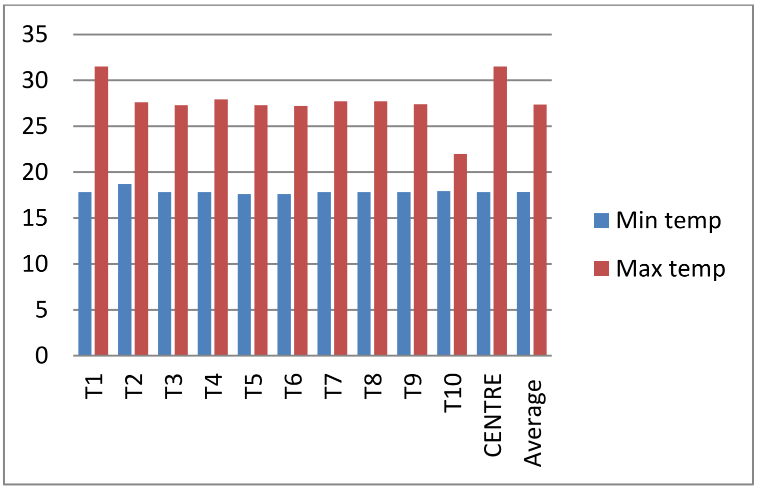


Table 82 show temperatures taken in the grade 6 classroom on 9 September 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) in the classroom is 17.6°C and is recorded at T5 postioned at the middle of class. The maximum temperature (taken in the afternoon -

14:00) in the classroom is 31.5°C and is recorded at T1 positioned at the centre front of class near to the door.

T1 – T3 : minimum and maximum temperature range from 17.8°C (08:00) to 31.5°C (14:00)

T4 – T6 : minimum and maximum temperature range from 17.6°C (08:00) to 27.3°C (14:00)

T8 – T9: minimum and maximum temperature range from 17.8°C (08:00) to 27.7°C (14:00)

The average for minimum and maximum temperatures for 9 September 2013 range from 17.9°C to 27.4°C between 08:00 and 14:00.

Table 83 Actual temperature at desk (T1-T10 & Centre) on 10/09/2013

10/09/2013	Min temp	Max temp
T1	20	29
T2	19.7	28
T3	20.2	28.9
T4	20	27.9
T5	19.9	28.4
T6	20	28
T7	20	27.6
T8	19	28
T9	19.9	28
T10	19.9	28
CENTRE	20	28
Average	**19.86**	**28.18**

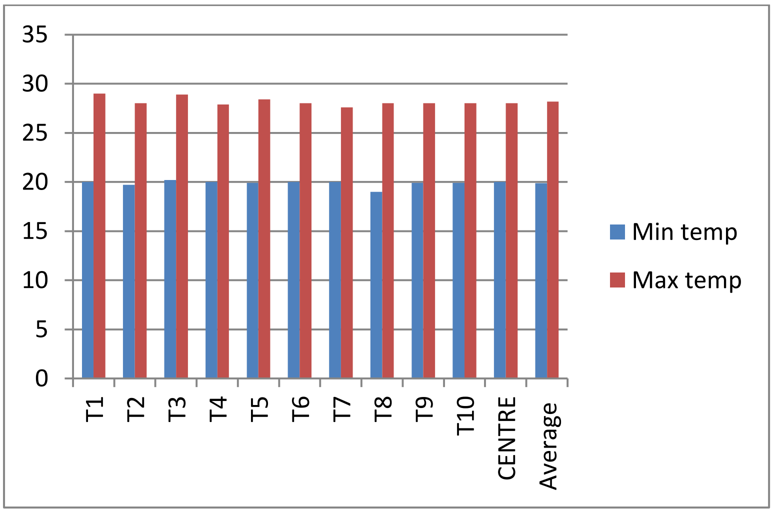


Table 83 show temperatures taken in the grade 6 classroom on 10 September 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) in the classroom is 19°C and is recorded at T8 postioned at the middle of class. The maximum temperature (taken in the afternoon - 14:00) in the classroom is 29°C and is recorded at T1 positioned at the front of class near to the door.

T1 – T3 : minimum and maximum temperature range from 19.7°C (08:00) to 29°C (14:00)

T4 – T6 : minimum and maximum temperature range from 19.9°C (08:00) to 28.4°C (14:00)

T8 – T9: minimum and maximum temperature range from 19°C (08:00) to 28°C (14:00)

The average for minimum and maximum temperatures for 10 September 2013 range from 19.9°C to 28.2°C between 08:00 and 14:00.

Table 84 Actual temperature at desk (T1-T10 & Centre) on 11/09/2013

11/09/2013	Min temp	Max temp
T1	20.3	29.1
T2	20	29.7
T3	20	28.9
T4	20.2	28
T5	N/R	N/R
T6	20	28.9
T7	19.9	27.7
T8	19.8	28
T9	19.9	28
T10	20	28
CENTRE	19.7	26.4
Average	**20.01**	**28.48**

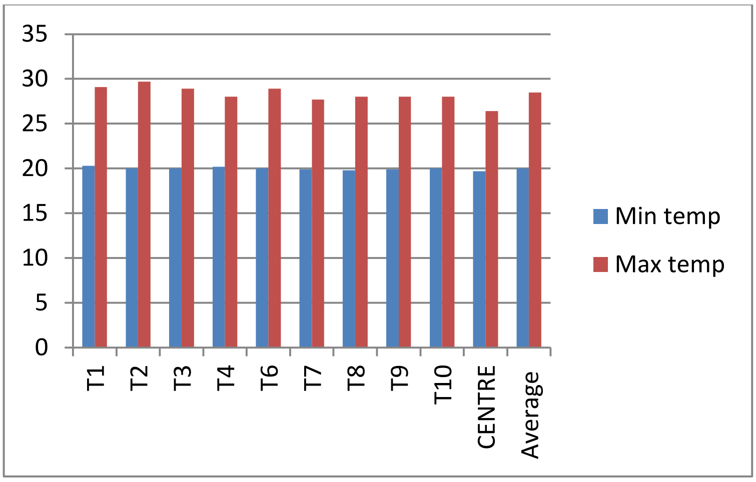


Table 84 show temperatures taken in the grade 6 classroom on 11 September 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) in the classroom is 19.8°C and is recorded at T8 postioned at the middle of class close to windows. The maximum temperature (taken in the afternoon - 14:00) in the classroom is 29.7°C and is recorded at T2 positioned at the front of class near to windows.

T1 – T3 : minimum and maximum temperature range from 20°C (08:00) to 29.7C (14:00)

T4 – T6 : minimum and maximum temperature range from 20°C (08:00) to 28.9°C (14:00) (T5 no reading)

T8 – T9: minimum and maximum temperature range from 19.9°C (08:00) to 28°C (14:00)

The average for minimum and maximum temperatures for 11 September 2013 range from 20.1°C to 28.5°C between 08:00 and 14:00.

Table 85 Actual temperature at desk (T1-T0 & CENTER) on 12/09/2013

12/09/2013	Min temp	Max temp
T1	21	26.6
T2	21	26
T3	21.8	27
T4	21	26
T5	24	27
T6	21.7	25
T7	21	25
T8	N/R	N/R
T9	21.5	36.8
T10	21.6	26
CENTRE	21	25
Average	**21.62**	**27.27**

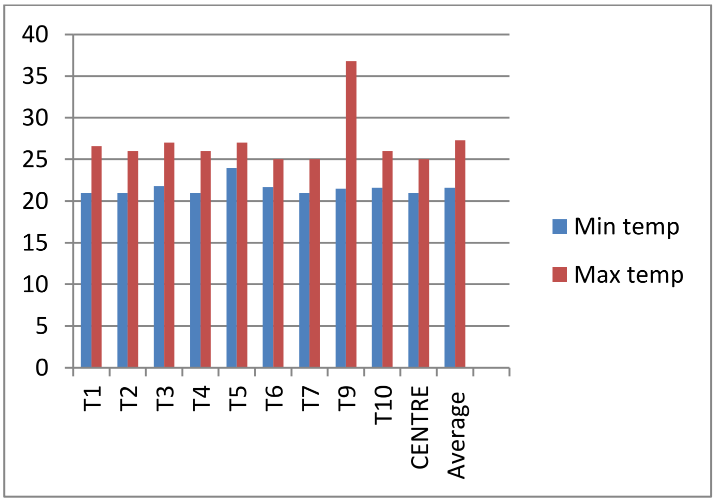


Table 85 show temperatures taken in the grade 6 classroom on 12 September 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) in the classroom is 21°C and is recorded at T1/T2/T7.The maximum temperature (taken in the afternoon - 14:00) in the classroom is 36.8°C and is recorded at T9.

T1 – T3 : minimum and maximum temperature range from 21°C (08:00) to 27°C (14:00)

T4 – T6 : minimum and maximum temperature range from 21°C (08:00) to 27°C (14:00)

T7 – T9: minimum and maximum temperature range from 21°C (08:00) to 36.8°C (14:00)(T8 no readings)

The average for minimum and maximum temperatures for 12 September 2013 range from 21.62°C to 27.27°C between 08:00 and 14:00.

Table 86 Actual temperature at desk (T1-T10 & Centre) on 13/09/2013

13/09/2013	Min temp	Max temp
T1	20.9	29.7
T2	21	26
T3	21.5	29
T4	20.9	28.7
T5	N/R	N/R
T6	21	29.6
T7	20.8	29.8
T8	21	23.6
T9	20.9	29
T10	20.9	30.7
CENTRE	N/R	N/R
Average	**20.98**	**28.46**

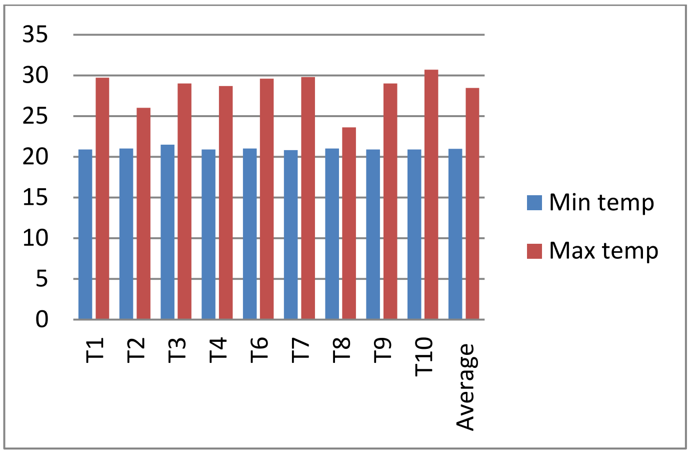


Table 86 show temperatures taken in the grade 6 classroom on 13 September 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) in the classroom is 21°C and is recorded at T7 postioned at the front of class close to windows. The maximum temperature (taken in the afternoon - 14:00) in the classroom is 29.8°C and is recorded at T10 positioned at the teacher's desk at the back of class.

T1 – T3 : minimum and maximum temperature range from 20.9°C (08:00) to 29.7°C (14:00)

T4 – T6 : minimum and maximum temperature range from 20.9°C (08:00) to 29.6°C (14:00) (T5-no readings)

T7 – T9: minimum and maximum temperature range from 20.9°C (08:00) to 29.8°C (14:00)

The average for minimum and maximum temperatures for 13 September 2013 ranges from 20.98°C to 28.5°C between 08:00 and 14:00.

11.1.4 **Case Study A: Botlhabatsatsi Primary Grade 7**

Table 87 Actual temperature at desk (T1-T10 & Centre) on 09/09/2013

09/09/2013	Min temp	Max temp
T1	17.9	28
T2	17.8	27.8
T3	17.8	28
T4	17.7	28.6
T5	17.6	29
T6	17.6	29
T7	17.6	28
T8	17.6	28
T9	17.9	27.8
T10	17.6	28.5
Teacher	17.9	27
Average	**17.71**	**28.27**

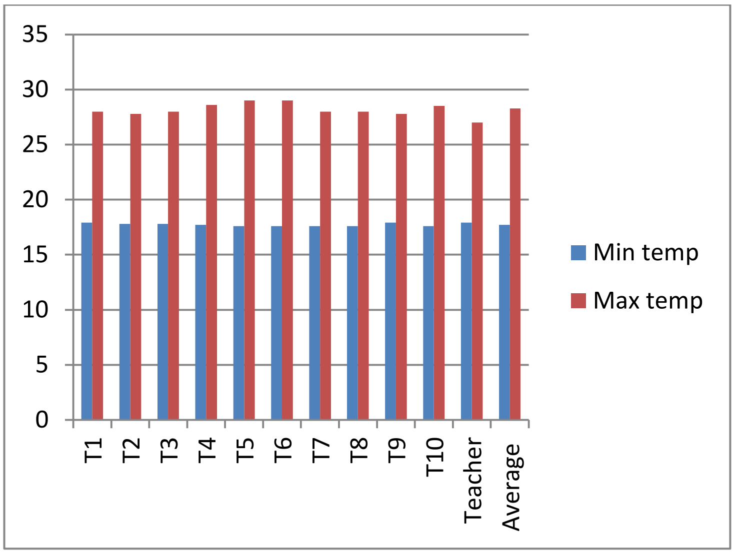


Table 87 show temperatures taken in the grade 7 classroom on the 9 September 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) in the classroom is 17.6°C and is recorded at T5 –T8/T10. The maximum temperature (taken in the afternoon - 14:00) in the classroom is 29°C and is recorded at T5/T9 positioned near to windows.

T1 – T3 : minimum and maximum temperature range from 17.8°C (08:00) to 28°C (14:00)

T4 – T6 : minimum and maximum temperature range from 17.6°C (08:00) to 29°C (14:00)

T7 – T9: minimum and maximum temperature range from 17.6°C (08:00) to 28°C (14:00)

The average for minimum and maximum temperatures for 9 September 2013 range from 17.7°C to 28.3°C.between 08:00 and 14:00.

Table 88 Actual temperature at desk (T1-T10 & Centre) on 10/09/2013

10/09/2013	Min temp	Max temp
T1	N/R	N/R
T2	19.9	28.2
T3	19.9	27.8
T4	20.3	28.3
T5	19.7	28
T6	19.6	28
T7	20.2	27.2
T8	N/R	N/R
T9	19.9	27.8
T10	19.5	26.8
Centre	20.1	27.5
Average	**19.88**	**27.76**

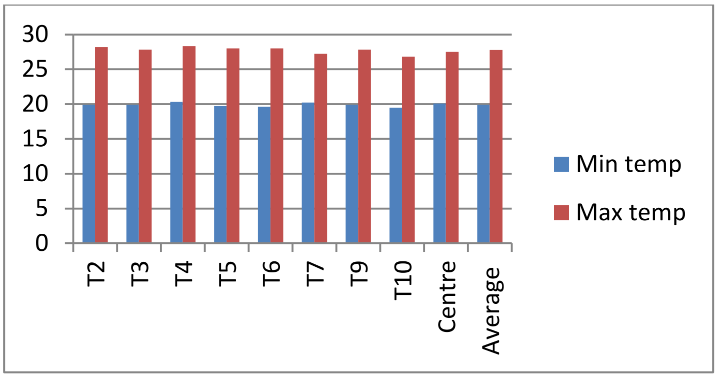


Table 88 show temperatures taken in the grade 7 classroom on 10 September 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) in the classroom is 19.5°C and is recorded at T10(Teacher's Desk)-postioned at the back corner of class. The maximum temperature (taken in the afternoon - 14:00) in the classroom is 28.3°C and is recorded at T5/T9 positioned near to windows.

T1 – T3 : minimum and maximum temperature range from 19.9°C (08:00) to 28.2°C (14:00) (T1 - No readings)

T4 – T6 : minimum and maximum temperature range from 19.6°C (08:00) to 28.3°C (14:00)

T7 – T10: minimum and maximum temperature range from 19.9°C (08:00) to 28°C (14:00) (T8 - No readings)

The average for minimum and maximum temperatures for 10 September 2013 range from 19.9°C to 27.8C.between 08:00 and 14:00.

Table 89 Actual temperature at desk (T1-T10 & Centre) on 11/102013

11/09/2013	Min temp	Max temp
T1	19.3	28.7
T2	19.3	28.7
T3	18.9	29
T4	19.1	28.6
T5	19.1	29.3
T6	19.9	28.1
T7	18.9	28.2
T8	19.4	29.4
T9	19.4	29
T10	19.7	29.8
Centre	18.9	28.4
Average	**19.3**	**28.88**

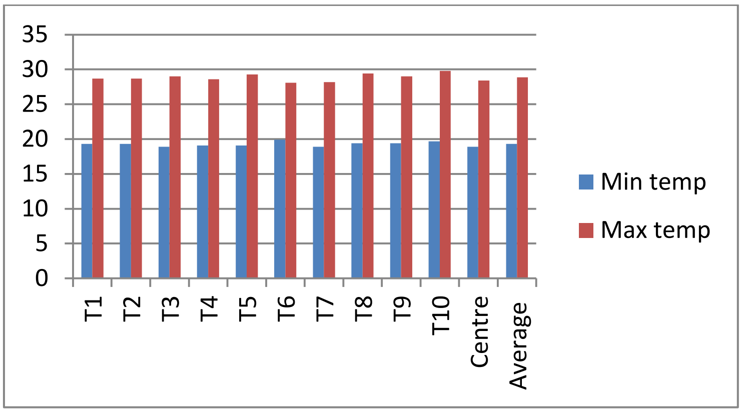


Table 89 show temperatures taken in the grade 7classroom on 11 September 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) in the classroom is 18.9°C and is recorded at T7.The maximum temperature (taken in the afternoon - 14:00) in the classroom is 29.8°C and is recorded at T10.

T1 – T3 : minimum and maximum temperature range from 18.9°C (08:00) to 29.3°C (14:00)

T4 – T6 : minimum and maximum temperature range from 19.1°C (08:00) to 28.3°C (14:00)

T7 – T10: minimum and maximum temperature range from 18.9°C (08:00) to 29.8°C (14:00)

The average for minimum and maximum temperatures for 11 September 2013 range from 19.3°C to 28.9°C between 08:00 and 14:00.

Table 90 Actual temperature at desk (T1-T10 & Centre) on 12/09/2013

12/09/2013	Min temp	Max temp
T1	20.6	26.6
T2	20.9	27.1
T3	20.9	28.8
T4	21.1	26.3
T5	21.2	26.9
T6	20.9	27.4
T7	20.9	27.1
T8	21.1	27.4
T9	21.1	26.9
T10	21.1	27.4
Centre	21.1	26.7
Average	**20.98**	**27.19**

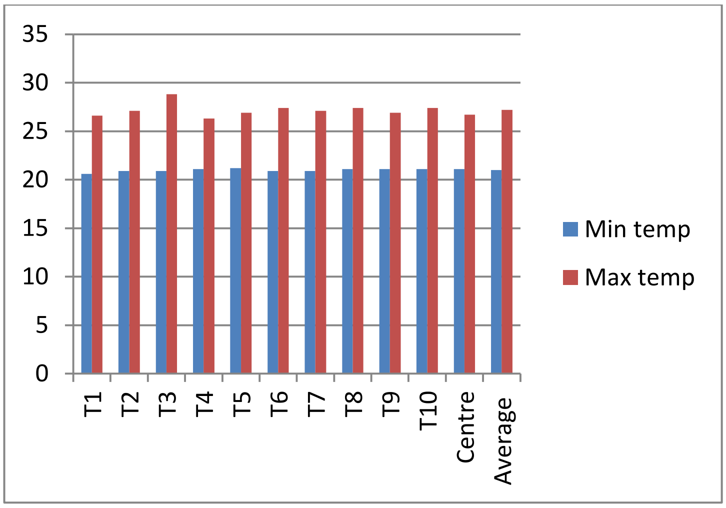


Table 90 show temperatures taken in the grade 7classroom on 12 September 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) in the classroom is 20.6°C and is recorded at T1. The maximum temperature (taken in the afternoon - 14:00) in the classroom is 28.8°C and is recorded at T3.

T1 – T3 : minimum and maximum temperature range from 20.6°C (08:00) to 28.8°C (14:00)

T4 – T6 : minimum and maximum temperature range from 20.9°C (08:00) to 27.4°C (14:00)

T7 – T10: minimum and maximum temperature range from 20.9°C (08:00) to 27.4°C (14:00)

The average for minimum and maximum temperatures for 12 September 2013 range from 20.9°C to 27.2°C between 08:00 and 14:00.

Table 91 Actual temperature at desk (T1-T10 & Centre) on 13/102013

13/09/2013	Min temp	Max temp
T1	20.8	29.3
T2	20.5	30.1
T3	20.6	28.3
T4	20.6	28.3
T5	20.7	29.7
T6	20.6	28.9
T7	20.7	29.1
T8	20.7	30.1
T9	20.7	29.4
T10	20.6	28.8
Centre	20.5	29.2
Average	**20.65**	**29.2**

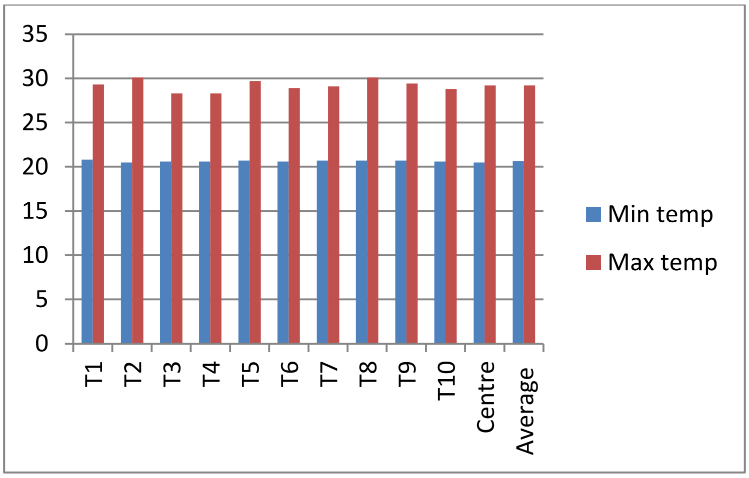


Table 91 show temperatures taken in the grade 7classroom on 13 September 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) in the classroom is 20.5°C and is recorded at T2. The maximum temperature (taken in the afternoon - 14:00) in the classroom is 30.1°C and is recorded at T2/T8.

T1 – T3 : minimum and maximum temperature range from 20.5°C (08:00) to 30.1°C (14:00)

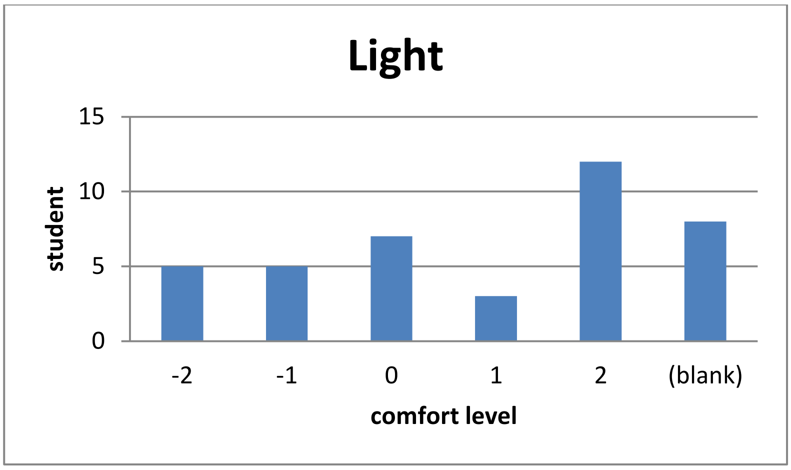
T4 – T6 : minimum and maximum temperature range from 20.6°C (08:00) to 29.7C (14:00)

T7 – T10: minimum and maximum temperature range from 20.6°C (08:00) to 30.1°C (14:00)

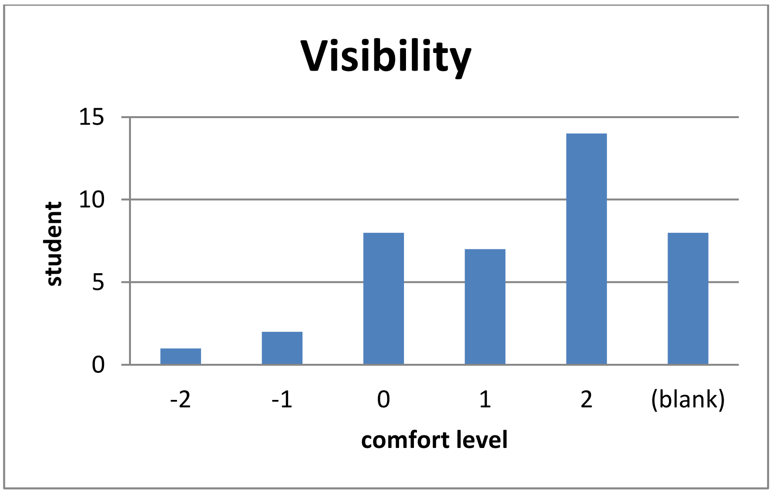
The average for minimum and maximum temperatures for 13 September 2013 range from 20.7°C to 29.2°C between 08:00 and 14:00.

Case study A: Grade 7 perceptions of indoor environment

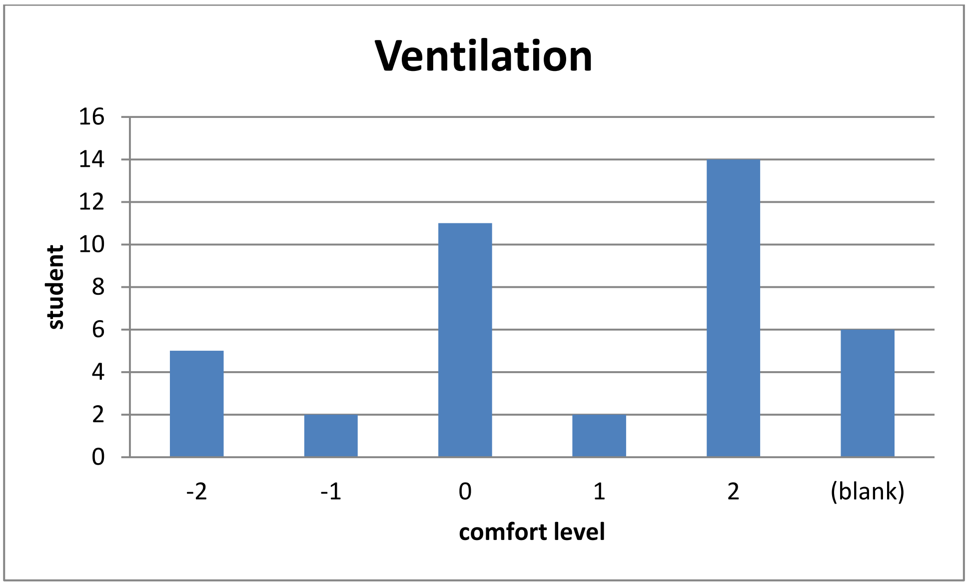
Majority of the learners were satisfied with the temperature in the classroom.



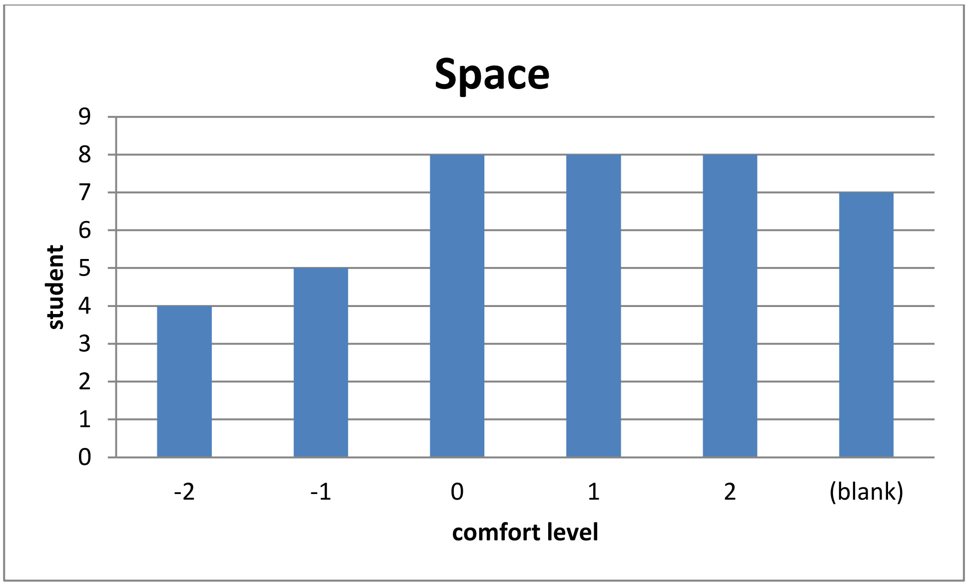
Majority of the learners were satisfied with the light level in the classroom.



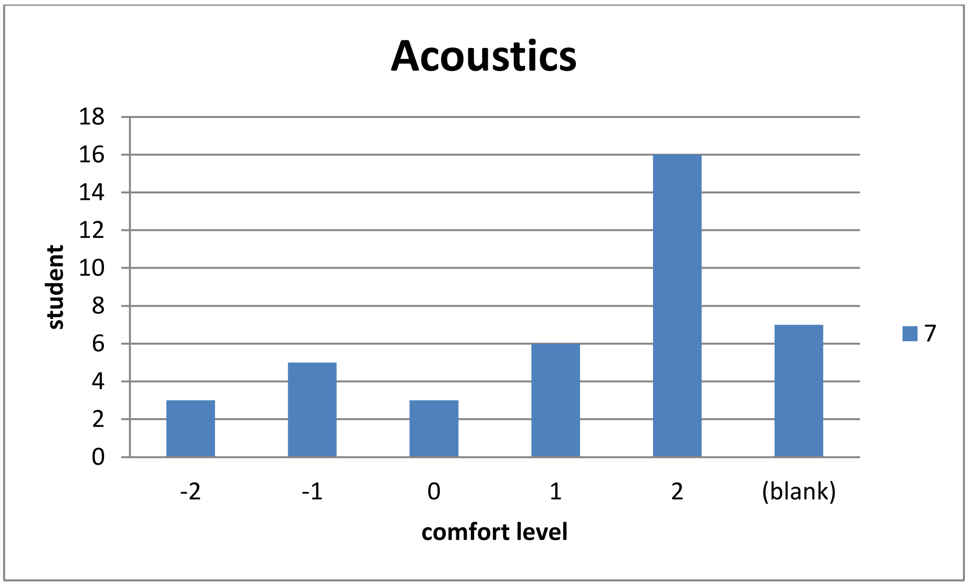
Majority of the learners agree that they could see what the teacher had written on the board.



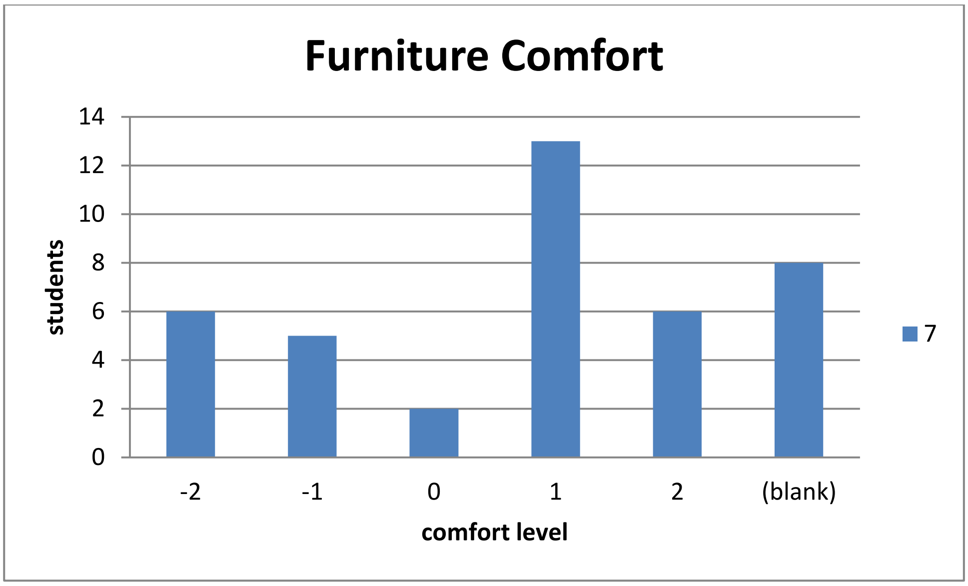
Majority of the learners agree that there is enough fresh air in the classroom.



Majority of the learners agree that they had enough work space.



Majority of the learners agree that they could hear the teacher from where they were seated.



Majority of the learners were satisfied with the comfort of the desks and chair

11.2 Case Study B: Meetse A Bophelo

11.2.1 Case study B: Statistics

MEETSE A BOPHELO PRIMARY SCHOOL 2013

GRADE R	BOYS	GIRLS	TOTAL	EDUCATOR
GRADE R (A)	16	19	35	Dimakatso
GRADE R (B)	18	15	33	Adelaide
GRADE R (C)	20	18	38	Khuki
GRADE R (D)	15	19	34	Thembi
TOTAL	**69**	**71**	**140**	

GRADE 1	BOYS	GIRLS	TOTAL	EDUCATOR
GRADE 1(A)	26	24	50	Xhosa
GRADE 1(B)	26	25	51	Fatlana
GRADE 1(C)	28	21	49	Nthute
GRADE 1(D)	37	14	51	Nyathi
GRADE 1(E)	29	19	48	Makgatlaneng
GRADE 1(F)	30	29	59	Dwando
GRADE 1(G)	33	27	60	Sithole
TOTAL	**209**	**159**	**368**	

GRADE 2	BOYS	GIRLS	TOTAL	EDUCATOR
GRADE 2(A)	30	21	51	
GRADE 2(B)	23	25	48	
GRADE 2(C)	25	31	56	
GRADE 2(D)	14	23	35	
GRADE 2(E)	15	20	35	
TOTAL	107	120	225	

GRADE 3	BOYS	GIRLS	TOTAL	EDUCATOR
GRADE 3(A)	30	23	53	
GRADE 3(B)	27	24	51	
GRADE 3(C)	25	25	50	
GRADE 3(D)	30	25	55	
TOTAL	**112**	**97**	**209**	

GRADE 4	BOYS	GIRLS	TOTAL	EDUCATORS
-				
GRADE 4(A)	18	40	58	
GRADE 4(B)	38	24	62	
GRADE 4(C)	35	24	59	
GRADE 4(D)	36	27	63	
TOTAL	**127**	**115**	**242**	

GRADE 5	BOYS	GIRLS	TOTAL	EDUCATORS
-				
GRADE 5(A)	27	25	52	
GRADE 5(B)	27	28	55	
GRADE 5(C)	23	34	57	
TOTAL	**77**	**87**	**164**	

GRADE 6	BOYS	GIRLS	TOTAL	EDUCATORS
-				
GRADE 6(A)	33	21	54	
GRADE 6(B)	31	29	60	
GRADE 6(C)	28	31	59	
TOTAL	**92**	**81**	**173**	

GRADE 7	BOYS	GIRLS	TOTAL	EDUCATORS
-				
GRADE 7(A)	25	35	60	MALEBO LANGA
GRADE 7(B)	24	36	50	
GRADE 7(C)	32	19	51	
GRADE 7(D)	27	23	50	
TOTAL	**108**	**113**	**211**	

11.2.2 Case Study B: Bothlabatsatsi Primary Grade 3D

Actual desk temperature measurements for grade 3D Desks from 2 October 2013 to 8 October 2013

Table 92 T1 maximum and minimum temperatures

T1 / Date	Min temp.	Max temp.
02/10/2013	16.8	29.2
03/10/2013	19.6	29.2
04/10/2013	18.9	29.2
05/10/2013	21.1	31.1
06/10/2013	21.8	32.1
07/10/2013	20.3	28.7
08/10/2013	19.1	29.4
Average	**19.65**	**29.84**

Table 92 shows temperatures taken in the classroom at the T1 from 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 16.8°C , recorded on 2 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 32.1°C , recorded on 6 October 2013. The average for minimum and maximum temperatures for T1 from 2 October 2013 to 8 October 2013 ranges from 19.7° C to 29.8°C between 08:00 and 14:00

Table 93 T2 maximum and minimum temperatures

T2 Date	Min temp.	Max temp.
02/10/2013	16.6	28.4
03/10/2013	20.2	31.6
04/10/2013	19.9	29.9
05/10/2013	21.2	30.9
06/10/2013	21.9	31.9
07/10/2013	20.1	29.9
08/10/2013	19.5	29.3
Average	**19.9**	**30.27**

Table 93 shows temperatures taken in the classroom at the T2 from 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 16.6°C , recorded on 2 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 31.9°C , recorded on 6 October 2013. The average for minimum and maximum temperatures for T2 from 2 October 2013 to 8 October 2013 ranges from 19.9° C to 30.3°C between 08:00 and 14:00.

Table 94 T3 maximum and minimum temperatures

T3 /Date	Min temp.	Max temp.
02/10/2013	16.8	30.8
03/10/2013	19.9	31.8
04/10/2013	19.8	30
05/10/2013	21.2	30.9
06/10/2013	21.9	31.9
07/10/2013	20.2	29.9
08/10/2013	19.3	29.1
Average	**19.87**	**30.6**

Table 94 shows temperatures taken in the classroom at the T3 from 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 19.3°C recorded on 8 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 31.9°C recorded on 6 October 2013. The average for minimum and maximum temperatures for T3 from 2 October 2013 to 8 October 2013 ranges from 19.9° C to 30.6°C between 08:00 and 14:00.

Table 95 T4 maximum and minimum temperatures

T4 /Date	Min temp.	Max temp.
02/10/2013	16.9	28.9
03/10/2013	19.9	31.3
04/10/2013	19.3	29.6
05/10/2013	20.9	30.8
06/10/2013	21.7	31.8
07/10/2013	20.2	29.6
08/10/2013	19.3	29.4
Average	**19.7**	**30.2**

Table 95 shows temperatures taken in the classroom at the T4 from 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 16.9°C, recorded on 2 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 31.8°C,

recorded on 6 October 2013. The average for minimum and maximum temperatures for T4 from 2 October 2013 to 8 October 2013 ranges from 19.7° C to 30.2°C between 08:00 and 14:00.

Table 96 T5 maximum and minimum temperatures

T5 /Date	Min temp.	Max temp.
02/10/2013	N/R	N/R
03/10/2013	19.9	31.3
04/10/2013	19.2	29.9
05/10/2013	20.8	30.5
06/10/2013	21.6	31.4
07/10/2013	20.3	29.3
08/10/2013	18.9	29.3
Average	**20.1**	**30.3**

Table 96 shows temperatures taken in the classroom at the T5 from 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 18.9°C, recorded on 8 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 31.4°C , recorded on 6 October 2013. The average for minimum and maximum temperatures for T5 from 2 October 2013 to 8 October 2013 ranges from 20.1° C to 30.3°C between 08:00 and 14:00.

Table 97 T6 maximum and minimum temperatures

Desk 6 Date	Min temp.	Max temp.
02/10/2013	N/R	N/R
03/10/2013	20.1	31.8
04/10/2013	19.4	30.4
05/10/2013	21.5	30.9
06/10/2013	21.9	31.9
07/10/2013	20.5	29.4
08/10/2013	19.5	29.3
Average	**20.5**	**30.6**

Table 97 shows temperatures taken in the classroom at the T6 from 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 19.4°C, recorded on 4 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 31.9°C,

recorded on 6 October 2013. No readings were recorded on 2 October 2013. The average for minimum and maximum temperatures for T6 from 2 October 2013 to 8 October 2013 ranges from 20.5° C to 30.6°C between 08:00 and 14:00.

Table 98 T7 maximum and minimum temperatures

T7 /Date	Min temp.	Max temp.
02/10/2013	17.8	29
03/10/2013	18.9	31.2
04/10/2013	19	28.9
05/10/2013	20.3	29.4
06/10/2013	21.1	30.4
07/10/2013	20.3	29.5
08/10/2013	18	29.4
Average	**19.3**	**29.7**

Table 98 shows temperatures taken in the classroom at the T7 from 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 17.8°C, recorded on 2 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 31.2°C , recorded on 3 October 2013. The average for minimum and maximum temperatures for T7 from 2 October 2013 to 8 October 2013 ranges from 19.3° C to 29.7°C between 08:00 and 14:00.

Table 99 T8 maximum and minimum temperatures

T8 /Date	Min temp.	Max temp.
02/10/2013	16.6	30.1
03/10/2013	19.4	31.9
04/10/2013	18.8	29.9
05/10/2013	20.4	30.2
06/10/2013	21.2	31.2
07/10/2013	20.4	29.9
08/10/2013	18.8	29.2
Average	**19.37**	**30.34**

Table 99 shows temperatures taken in the classroom at the T8 from 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 16.6°C, recorded on 2 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 31.9°C, recorded on 3 October 2013. The average for minimum and maximum temperatures for T8 from 2 October 2013 to 8 October 2013 ranges from 19.4° C to 30.3°C between 08:00 and 14:00.

Table 100 T9 maximum and minimum temperatures

T9 /Date	Min temp.	Max temp.
02/10/2013	16.7	29.8
03/10/2013	19.2	31.5
04/10/2013	18.8	30.1
05/10/2013	20.6	30.1
06/10/2013	21.4	31.1
07/10/2013	20.5	29.2
08/10/2013	18.8	24.4
Average	**19.43**	**29.4**

Table 100 shows temperatures taken in the classroom at the T9 from 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 16.7°C recorded on 2 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 31.5°C recorded on 3 October 2013. The average for minimum and maximum temperatures for T9 from 2 October 2013 to 8 October 2013 ranges from 19.43° C to 29.4°C between 08:00 and 14:00.

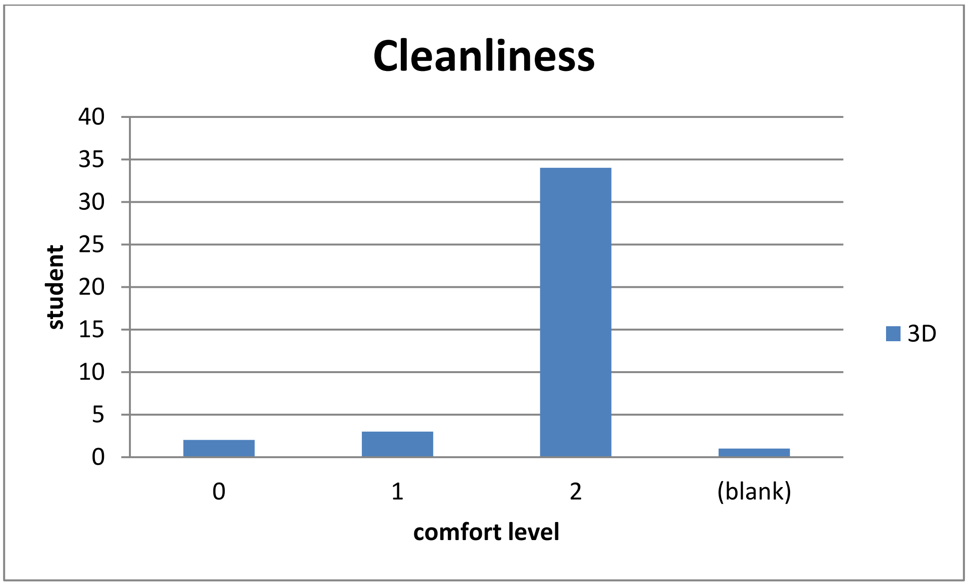
Table 101 T10 maximum and minimum temperatures

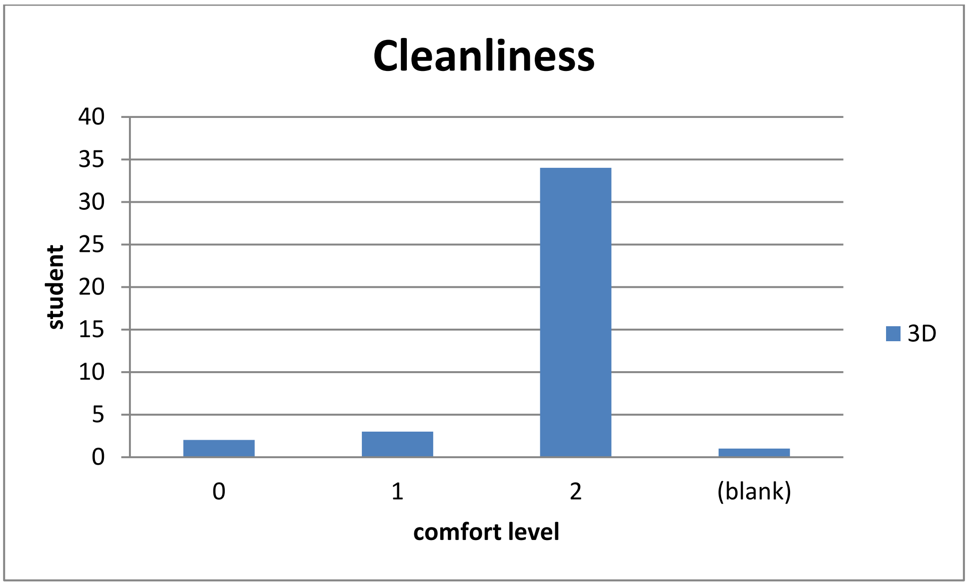
T10/ Date	Min temp.	Max temp.
02/10/2013	17.1	28.8
03/10/2013	19.9	32.1
04/10/2013	19.2	30.3
05/10/2013	21.2	31.7
06/10/2013	21.9	32.8
07/10/2013	20.3	30.5
08/10/2013	19.4	0
Average	**19.85**	**31.03**

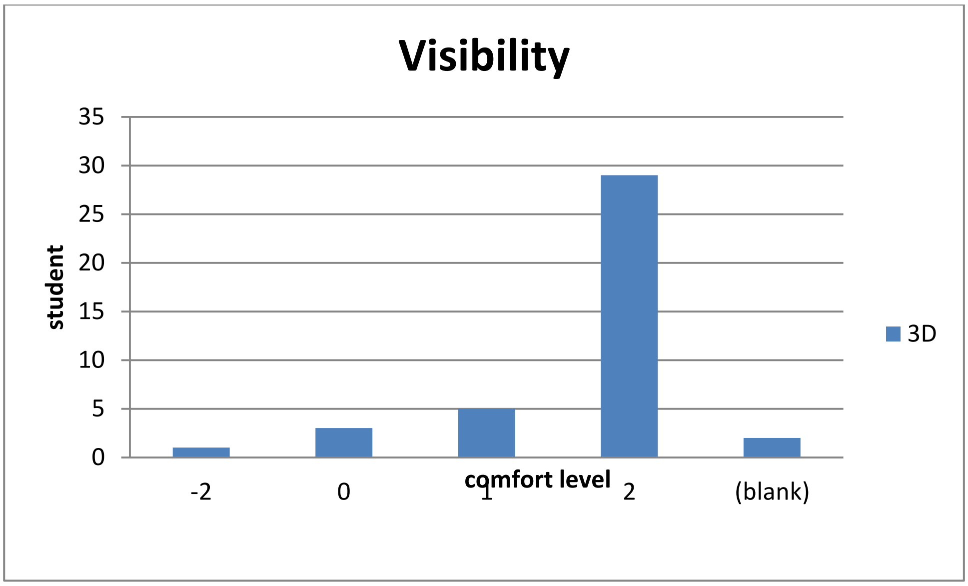
Table 101 shows temperatures taken in the classroom at the T10 from 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 17.1°C recorded on 2 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 32.8°C recorded on 6 October 2013. The average for minimum and maximum temperatures for T10 from 2 October 2013 to 8 October 2013 ranges from 19.9° C to 31.03°C between 08:00 and 14:00. The teachers desk is close to the window.

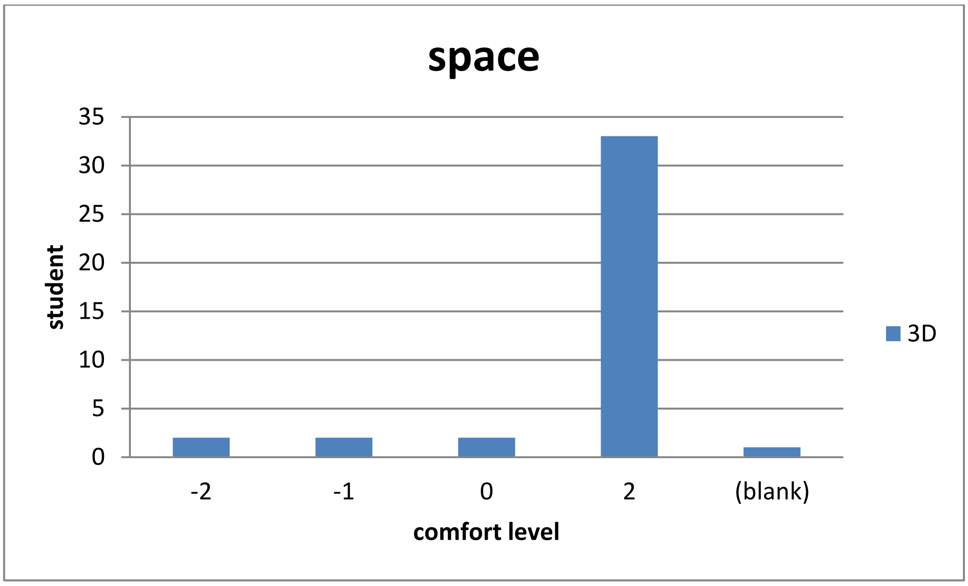
Case study B: Grade 3 learner perception

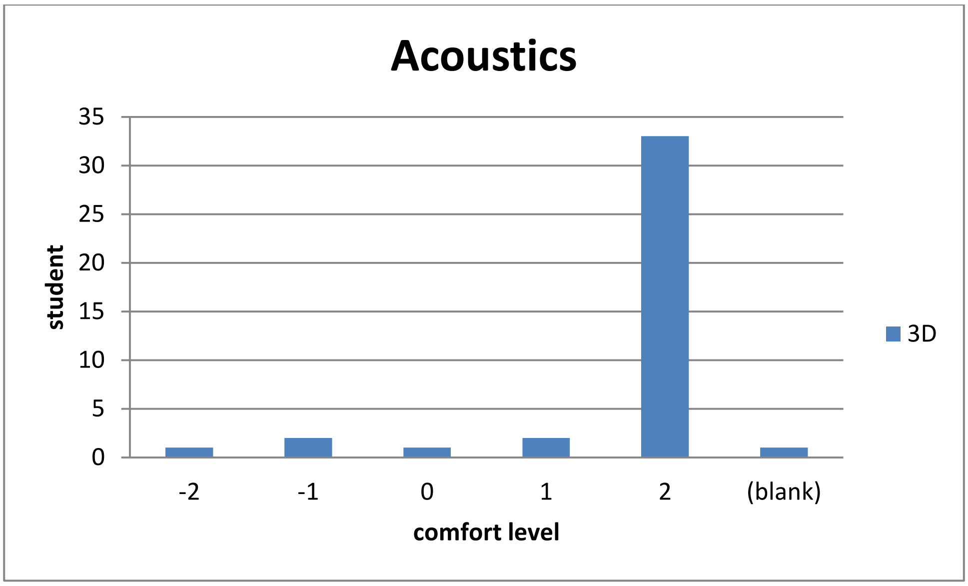
Date 12/10/2013

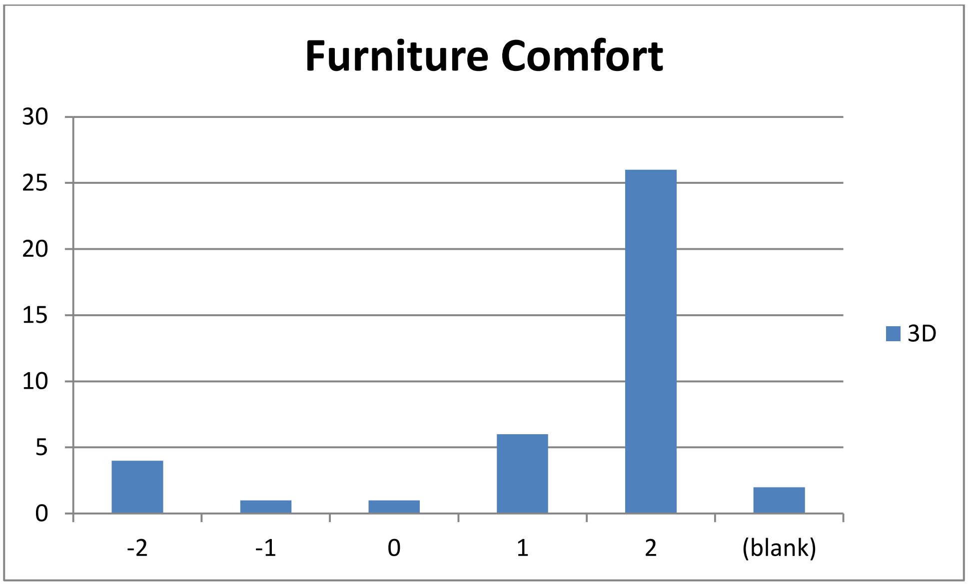



Cleanliness
40
35
30
25
20
15
10
5
0
student
0
1
2
(blank)
comfort level
3D

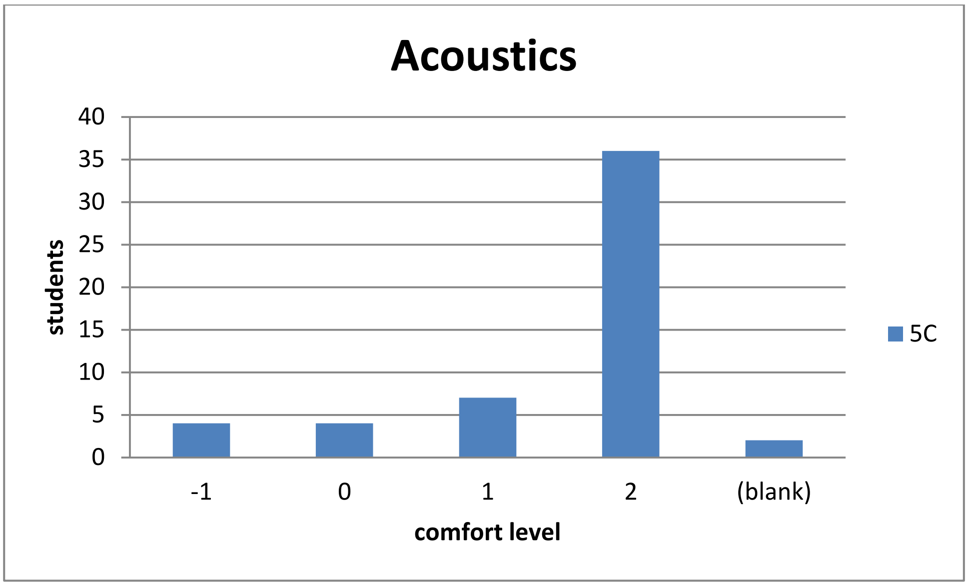

Visibility
35
30
25
20
15
10
5
0
student
-2
0
1
2
(blank)
comfort level
3D

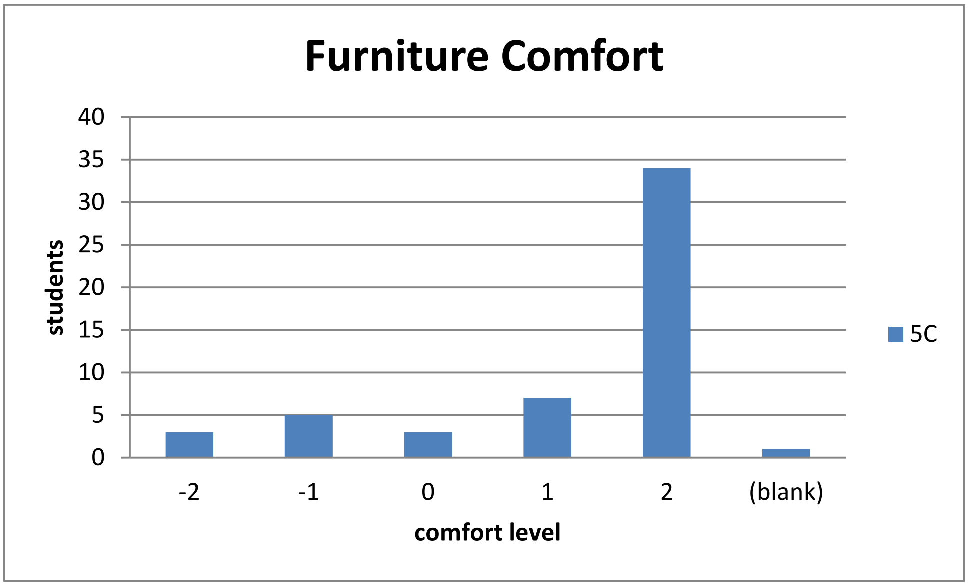

space
35
30
25
20
15
10
5
0
student
-2
-1
0
2
(blank)
comfort level
3D

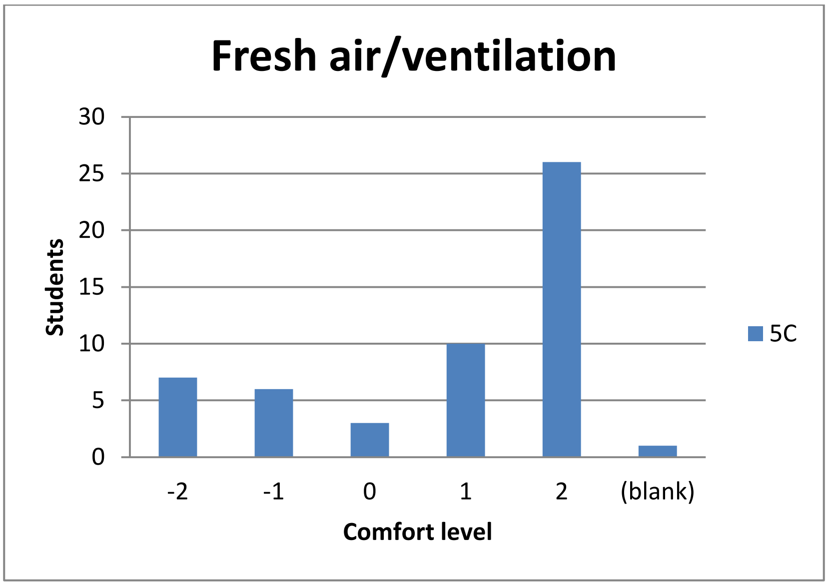

Acoustics
35
30
25
20
15
10
5
0
student
-2
-1
0
1
2
(blank)
comfort level
3D

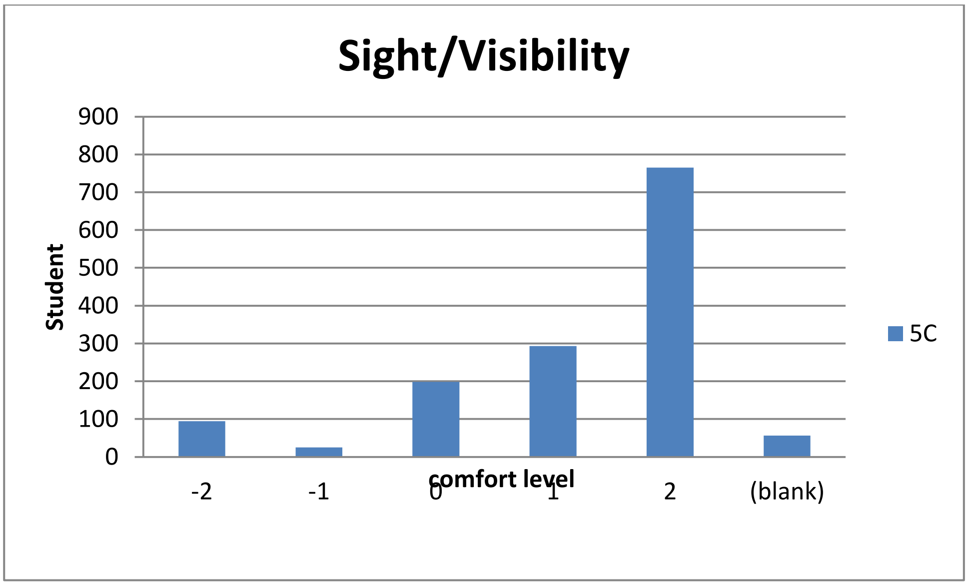

Furniture Comfort
30
25
20
15
10
5
0
-2
-1
0
1
2
(blank)
3D

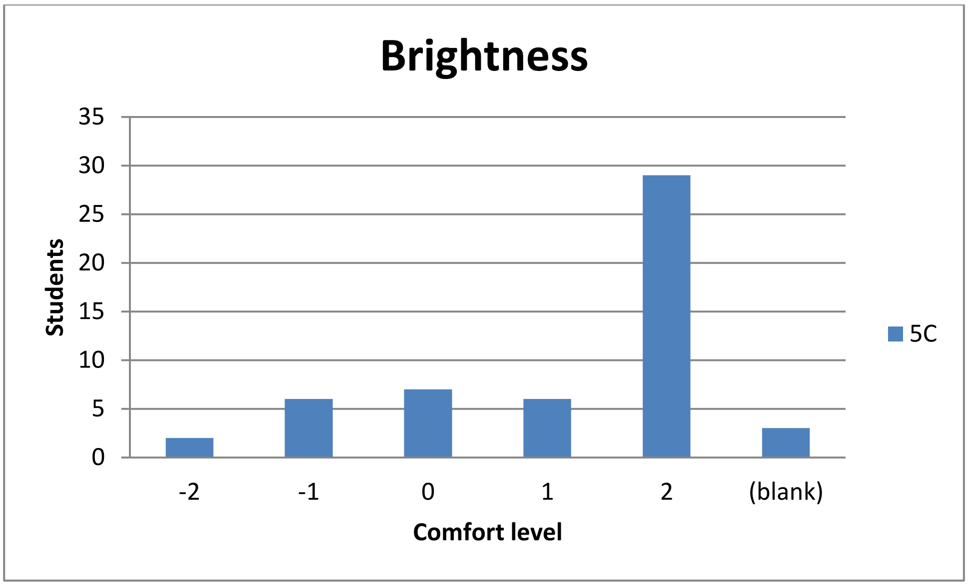
Case study B: Grade 5A Learner perception

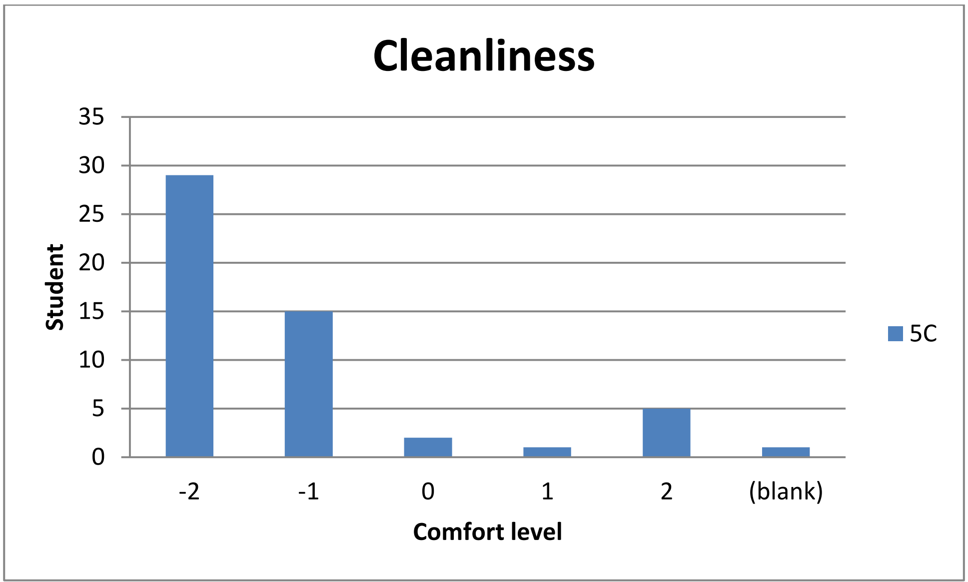





Fresh air/ventilation
Students
30
25
20
15
10
5
0
-2
-1
0
1
2
(blank)
Comfort level
5C


Sight/Visibility
Student
900
800
700
600
500
400
300
200
100
0
-2
-1
0
1
2
(blank)
comfort level
5C


Brightness
Students
35
30
25
20
15
10
5
0
-2
-1
0
1
2
(blank)
Comfort level
5C



11.2.3 **Case Study B: Meetse a Bophelo Primary Grade 4D**

<u>Actual desk temperature measurements for grade 4D Desks from 2 October 2013 to 8 October 2013</u>

Table 102 T1 maximum and minimum temperatures

T1/ Date	Min temp.	Max temp.
02/10/2013	15.9	28.8
03/10/2013	19.8	30.9
04/10/2013	19.2	30
05/10/2013	20.1	28.9
06/10/2013	20.9	30.9
07/10/2013	19.6	30.5
08/10/2013	18.6	29.2
Average	**19.2**	**29.9**

Table 102 shows temperatures taken in the classroom at the T1 from 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 15.9°C , recorded on 2 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 30.9°C , recorded on 7 October 2013. The average for minimum and maximum temperatures for T1 from 2 October 2013 to 8 October 2013 ranges from 19.2° C to 29.9°C between 08:00 and 14:00.

Table 103 T2 maximum and minimum temperatures

T2 /Date	Min temp.	Max temp.
02/10/2013	15.8	28.9
03/10/2013	19.6	31.2
04/10/2013	19.2	29.9
05/10/2013	19.9	28.3
06/10/2013	20.7	30.3
07/10/2013	19.7	30.8
08/10/2013	18.4	29.3
Average	**19.04**	**29.81**

Table 103 shows temperatures taken in the classroom at the T2 from 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 15.8°C , recorded on 2 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 31.2°C , recorded on 6 October 2013. The average for minimum and maximum temperatures for T2 from 2 October 2013 to 8 October 2013 ranges from 19.04° C to 29.8°C between 08:00 and 14:00.

Table 104 T3 maximum and minimum temperatures

T3/Date	Min temp.	Max temp.
02/10/2013	15.9	28.7
03/10/2013	19.9	32.6
04/10/2013	18.9	31.2
05/10/2013	20.1	30.6
06/10/2013	20.9	32.6
07/10/2013	20	30.8
08/10/2013	19.1	29.1
Average	**19.3**	**30.8**

Table 104 shows temperatures taken in the classroom at the T3 from 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 15.9°C , recorded on 2 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 32.°C , recorded on 2 October 2013 and 6 October 2013. The average for minimum and maximum temperatures for T3 from 2 October 2013 to 8 October 2013 ranges from 19.3° C to 30.8°C between 08:00 and 14:00.

Table 105 T4 maximum and minimum temperatures

T4 /Date	Min temp.	Max temp.
02/10/2013	15.9	29.5
03/10/2013	19.5	30.5
04/10/2013	18.9	29.4
05/10/2013	20	28.7
06/10/2013	20.6	30.1
07/10/2013	19.4	30
08/10/2013	18.1	29
Average	**18.9**	**29.6**

Table 105 shows temperatures taken in the classroom at the T4 from 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 15.9°C, recorded on 2 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 30.5°C, recorded on 3 October 2013. The average for minimum and maximum temperatures for T4 from 2 October 2013 to 8 October 2013 ranges from 18.9° C to 29.6°C between 08:00 and 14:00.

Table 106 T5 maximum and minimum temperatures

T5/ Date	Min temp.	Max temp.
02/10/2013	15.7	28.4
03/10/2013	19.7	31.1
04/10/2013	18.8	30.3
05/10/2013	19.9	28.6
06/10/2013	20.7	30.5
07/10/2013	19.3	30.7
08/10/2013	18.1	29.5
Average	**18.9**	**29.9**

Table 106 shows temperatures taken in the classroom at the T5 from 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 15.7°C, recorded on 2 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 31.1°C,

recorded on 3 October 2013. The average for minimum and maximum temperatures for T5 from 2 October 2013 to 8 October 2013 ranges from 18.9° C to 29.9°C between 08:00 and 14:00.

Table 107 T6 maximum and minimum temperatures

T6 /Date	Min temp.	Max temp.
02/10/2013	15.9	29.2
03/10/2013	19.7	31.9
04/10/2013	18.8	30.1
05/10/2013	19.9	28.5
06/10/2013	20.6	30.5
07/10/2013	19.7	30.6
08/10/2013	18.6	29.1
Average	**19.02**	**29.9**

Table 107 shows temperatures taken in the classroom at the T6 from 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 15.9°C, recorded on 2 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 31.9°C, recorded on 3 October 2013. The average for minimum and maximum temperatures for T6 from 2 October 2013 to 8 October 2013 ranges from 19.02° C to 29.9°C between 08:00 and 14:00.

Table 108 T7 maximum and minimum temperatures

T7/ Date	Min temp.	Max temp.
02/10/2013	15.9	28.5
03/10/2013	19.6	30.5
04/10/2013	18.9	29.4
05/10/2013	19.9	28.8
06/10/2013	20.6	30.8
07/10/2013	19.6	30.3
08/10/2013	18.8	17.8
Average	**19.04**	**28.01**

Table 108 shows temperatures taken in the classroom at the T7 from 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 15.9°C, recorded on 2 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 30.8°C,

recorded on 6 October 2013. The average for minimum and maximum temperatures for T7 from 2 October 2013 to 8 October 2013 ranges from 19.04° C to 28.01°C between 08:00 and 14:00.

Table 109 T8 maximum and minimum temperatures

T8 /Date	Min temp.	Max temp.
02/10/2013	16.1	28.9
03/10/2013	19.4	30.4
04/10/2013	18.4	29.9
05/10/2013	19.6	28.3
06/10/2013	20.3	30.2
07/10/2013	19.4	30.5
08/10/2013	17.9	29.1
Average	**18.7**	**29.6**

Table 109 shows temperatures taken in the classroom at the T8 from 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 16.1°C, recorded on 2 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 30.5°C, recorded on 6 October 2013. The average for minimum and maximum temperatures for T1 from 2 October 2013 to 8 October 2013 ranges from 18.7° C to 29.6°C between 08:00 and 14:00.

Table 110 T1 maximum and minimum temperatures

T9/ Date	Min temp.	Max temp.
02/10/2013	15.8	28.6
03/10/2013	19.5	30.8
04/10/2013	18.2	29.8
05/10/2013	19.4	27.9
06/10/2013	20.2	29.9
07/10/2013	19.6	30.6
08/10/2013	17.9	20.1
Average	**18.65**	**28.2**

Table 110 shows temperatures taken in the classroom at the T9 from 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 15.8°C, recorded on 2 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 30.8°C,

recorded on 3 October 2013. The average for minimum and maximum temperatures for T9 from 2 October 2013 to 8 October 2013 ranges from 18.7° C to 28.2°C between 08:00 and 14:00.

Table 111 T1 maximum and minimum temperatures

T10/ Date	Min temp.	Max temp.
02/10/2013	16.4	30.3
03/10/2013	19.1	30.8
04/10/2013	18.7	30.1
05/10/2013	20	30.1
06/10/2013	20.8	31.9
07/10/2013	19.8	31.1
08/10/2013	17.9	29.2
Average	**18.95**	**30.5**

Table 111 shows temperatures taken in the classroom at the T10 from 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 16.4°C, recorded on 2 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 31.9°C, recorded on 6 October 2013. The average for minimum and maximum temperatures for T10 from 2 October 2013 to 8 October 2013 ranges from 18.9° C to 30.5°C between 08:00 and 14:00.

11.2.4 Case Study B: Meetse a Bophelo Primary Grade 5A

Actual desk temperature measurements for grade 5C Desks from 2 October 2013 to 8 October 2013

Table 112 T1 maximum and minimum temperatures

T1/ Date	Min temp.	Max temp.
02/10/2013	N/R	N/R
03/10/2013	N/R	N/R
04/10/2013	19.4	29.6
05/10/2013	20.5	28.6
06/10/2013	21.2	30.8
07/10/2013	20.7	30.5
08/10/2013	18.4	28.5
Average	**20.04**	**29.6**

Table 112 shows temperatures taken in the classroom at the T1 from 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 18.4°C, recorded on 8 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 30.8°C, recorded on 6 October 2013. The average for minimum and maximum temperatures for T1 from 2 October 2013 to 8 October 2013 ranges from 20.04° C to 29.6°C between 08:00 and 14:00. There were no readings taken on T1 on 2 October 2013 and 3 October 2013.

Table 113 T2 maximum and minimum temperatures

T2/ Date	Min temp.	Max temp.
02/10/2013	0	0
03/10/2013	0	0
04/10/2013	20.1	30.2
05/10/2013	20.4	28.5
06/10/2013	20.9	30.9
07/10/2013	20.7	30.9
08/10/2013	20.8	27.9
Average	**20.58**	**29.7**

Table 113 shows temperatures taken in the classroom at the T2 from 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 20.1°C, recorded on 4 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 30.9°C, recorded on 7 October 2013. The average for minimum and maximum temperatures for T2 from 4 October 2013 to 8 October 2013 ranges from 20.6° C to 29.7°C between 08:00 and 14:00. There were no readings taken on T2 on 2 October 2013 and 3 October 2013.

Table 114 T3 maximum and minimum temperatures

T3 /Date	Min temp.	Max temp.
02/10/2013	N/R	N/R
03/10/2013	N/R	N/R
04/10/2013	18.9	31.2
05/10/2013	20.1	30.6
06/10/2013	20.9	32.6
07/10/2013	20	30.8
08/10/2013	19.1	29.1
Average	**19.8**	**30.86**

Table 114 shows temperatures taken in the classroom at the T3 from 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 18.9°C, recorded on 4 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 32.6°C, recorded on 6 October 2013. The average for minimum and maximum temperatures for T3 from 4 October 2013 to 8 October 2013 ranges from 19.8° C to 30.9°C between 08:00 and 14:00. There were no readings taken on T3 on 2 October 2013 and 3 October 2013.

Table 115 T4 maximum and minimum temperatures

T4/ Date	Min temp.	Max temp.
02/10/2013	N/R	N/R
03/10/2013	N/R	N/R
04/10/2013	19.9	29.9
05/10/2013	20.3	28.8
06/10/2013	20.9	30.5

07/10/2013	20.5	30.4
08/10/2013	20.9	27.4
Average	**20.5**	**29.4**

Table 115 shows temperatures taken in the classroom at the T4 from 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 19.9°C, recorded on 4 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 30.5°C, recorded on 7 October 2013. The average for minimum and maximum temperatures for T4 from 4 October 2013 to 8 October 2013 ranges from 20.5° C to 29.4°C between 08:00 and 14:00. There were no readings taken on T4 on 2 October 2013 and 03/10/2013.

Table 116 T5 maximum and minimum temperatures

T5 /Date	Min temp.	Max temp.
02/10/2013	N/R	N/R
03/10/2013	N/R	N/R
04/10/2013	20.4	30.3
05/10/2013	20.6	29.1
06/10/2013	21.3	31.1
07/10/2013	21.1	31.2
08/10/2013	20.3	28.8
Average	**20.74**	**30.1**

Table 116 shows temperatures taken in the classroom at the T5 from 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 20.3°C, recorded on 4 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 31.2°C, recorded on 7 October 2013. The average for minimum and maximum temperatures for T5 from 4 October 2013 to 8 October 2013 ranges from 20.7 C to 30.1°C between 08:00 and 14:00. There were no readings taken on T5 on 2 October 2013 and 3 October 2013.

Table 117 T6 maximum and minimum temperatures

T6 /Date	Min temp.	Max temp.
02/10/2013	N/R	N/R
03/10/2013	N/R	N/R
04/10/2013	20.3	29.9
05/10/2013	20.8	28.9
06/10/2013	21.5	31.1
07/10/2013	20.3	31.1
08/10/2013	20.2	28.4
Average	**20.62**	**29.88**

Table 117 shows temperatures taken in the classroom at the T6 from the 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 20.2°C, recorded on 8 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 31.1°C, recorded on 6 October 2013 and 7 October 2013. The average for minimum and maximum temperatures for T6 from 4 October 2013 to 8 October 2013 ranges from 20.6° C to 29.9°C between 08:00 and 14:00. There were no readings taken on T6 on 2 October 2013 and 3 October 2013.

Table 118 T7 maximum and minimum temperatures

T7 /Date	Min temp.	Max temp.
02/10/2013	N/R	N/R
03/10/2013	N/R	N/R
04/10/2013	20.8	29.9
05/10/2013	20.9	29.5
06/10/2013	21.7	31.7
07/10/2013	21.1	31.1
08/10/2013	20.3	27.9
Average	**20.96**	**30.02**

Table 118 shows temperatures taken in the classroom at the T7 from the 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 20.3°C, recorded on 8 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 31.7°C, recorded on 6 October 2013. The average for minimum and maximum temperatures for T7 from 4

October 2013 to 8 October 2013 ranges from 20.96° C to 30°C between 08:00 and 14:00. There were no readings taken on T7 on 2 October 2013 and 3 October 2013.

Table 119 T8 maximum and minimum temperatures

T8/ Date	Min temp.	Max temp.
02/10/2013	N/R	N/R
03/10/2013	N/R	N/R
04/10/2013	20.9	29.7
05/10/2013	21.2	29.1
06/10/2013	21.9	31.4
07/10/2013	20.7	30.7
08/10/2013	20.5	27.9
Average	**21.04**	**29.76**

Table 119 shows temperatures taken in the classroom at the T8 from the 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 20.5°C, recorded on 4 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 31.4°C, recorded on 6 October 2013. The average for minimum and maximum temperatures for T8 from 4 October 2013 to 8 October 2013 ranges from 21.04° C to 29.8°C between 08:00 and 14:00. There were no readings taken on T8 on 2 October 2013 and 3 October 2013.

Table 120 T9 maximum and minimum temperatures

T9 /Date	Min temp.	Max temp.
02/10/2013	N/R	N/R
03/10/2013	N/R	N/R
04/10/2013	20.5	29.2
05/10/2013	20.9	28.1
06/10/2013	21.7	30.4
07/10/2013	20.7	30.4
08/10/2013	21.1	27.8
Average	**20.98**	**29.18**

Table 120 shows temperatures taken in the classroom at the T9 from the 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 20.5°C, recorded on 4 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 30.4°C, recorded on 6 October 2013 and 7 October 2013. The average for minimum and maximum temperatures for T9 from 4 October 2013 to 8 October 2013 ranges from 20.9° C to 29.2°C between 08:00 and 14:00. There were no readings taken on T2 on 2 October 2013 and 3 October 2013.

Table 121 T10 maximum and minimum temperatures

T10/ Date	Min temp.	Max temp.
02/10/2013	N/R	N/R
03/10/2013	N/R	N/R
04/10/2013	20.2	30.1
05/10/2013	20.9	29.6
06/10/2013	21.7	31.7
07/10/2013	20.8	31.5
08/10/2013	19.9	28.2
Average	**20.7**	**30.22**

Table 121 shows temperatures taken in the classroom at the T10 from the 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 19.9°C, recorded on 8 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 31.5°C, recorded on 7 October 2013. The average for minimum and maximum temperatures for T10 from 4 October 2013 to 8 October 2013 ranges from 20.7° C to 30.2°C between 08:00 and 14:00. There were no readings taken on T2 on 2 October 2013 and 3 October 2013.

11.2.5 Case Study B: Meetse a Bophelo Primary Grade 7A

Actual desk temperature measurements for grade 7A Desks from 2 October 2013 to 8 October 2013

Table 122 T1 minimum and maximum temperatures

T1/Date	Min temp.	Max temp.
02/10/2013	N/R	N/R
03/10/2013	N/R	N/R
04/10/2013	21.2	29.7
05/10/2013	20.9	28.9
06/10/2013	21.6	26.5
07/10/2013	20.9	30.6
08/10/2013	20.5	26.8
Average	**21.02**	**28.5**

Table 122 shows temperatures taken in the classroom at the T1 from the 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 20.5°C, recorded on 8 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 30.6°C, recorded on 7 October 2013. No data was recorded on 2 October 2013 to 3 October 2013. The average for minimum and maximum temperatures for T1 from 4 October 2013 to 8 October 2013 ranges from 21.2° C to 28.5°C between 08:00 and 14:00.

Table 123 T2 minimum and maximum temperatures

T2/ Date	Min temp.	Max temp.
02/10/2013	N/R	N/R
03/10/2013	N/R	N/R
04/10/2013	19.1	24.7
05/10/2013	20.8	29.1
06/10/2013	21.6	31.2
07/10/2013	21.1	30.2
08/10/2013	20.9	26.8
Average	**20.7**	**28.4**

Table 123 shows temperatures taken in the classroom at the T2 from the 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 19.1°C, recorded on 4 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 31.2°C, recorded on 6 October 2013. No data was recorded on 2 October 2013 to 3 October 2013. The average for minimum and maximum temperatures for T2 from 2 October 2013 to 8 October 2013 ranges from 20.7° C to 28.4°C between 08:00 and 14:00.

Table 124 T3 minimum and maximum temperatures

T3/ Date	Min temp.	Max temp.
02/10/2013	N/R	N/R
03/10/2013	N/R	N/R
04/10/2013	19.7	30.9
05/10/2013	21.1	30.1
06/10/2013	21.9	32.5
07/10/2013	20.9	30.6
08/10/2013	19.9	27.7
Average	**20.7**	**30.36**

Table 124 shows temperatures taken in the classroom at the T3 from the 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 19.7°C, recorded on 4 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 32.5°C, recorded on 6 October 2013. No data was recorded on 2 October 2013 to 3 October 2013. The average for minimum and maximum temperatures for T3 from 2 October 2013 to 8 October 2013 ranges from 20.7° C to 30.4°C between 08:00 and 14:00.

Table 125 T4 minimum and maximum temperatures

T4 /Date	Min temp.	Max temp.
02/10/2013	N/R	N/R
03/10/2013	N/R	N/R
04/10/2013	20.1	29.9
05/10/2013	20.6	28.9

06/10/2013	21.3	31.4
07/10/2013	20.9	31.6
08/10/2013	20.4	27.4
Average	**20.66**	**29.84**

Table 125 shows temperatures taken in the classroom at the T4 from 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 20.1°C, recorded on 4 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 31.4°C, recorded on 6 October 2013. No data was recorded on 2 October 2013 to 3 October 2013. The average for minimum and maximum temperatures for T4 from 2 October 2013 to 8 October 2013 ranges from 20.6° C to 29.8°C between 08:00 and 14:00.

Table 126 T5 minimum and maximum temperatures

T5 /Date	Min temp.	Max temp.
02/10/2013	N/R	N/R
03/10/2013	N/R	N/R
04/10/2013	19.9	30.7
05/10/2013	20.9	29.6
06/10/2013	21.8	31.3
07/10/2013	21.9	32.6
08/10/2013	21.4	26.7
Average	**21.18**	**30.18**

Table 126 shows temperatures taken in the classroom at the T5 from 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 19.9°C, recorded on 4 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 32.6°C, recorded on 7 October 2013. No data was recorded on 2 October 2013 to 3 October 2013. The average for minimum and maximum temperatures for T5 from 2 October 2013 to 8 October 2013 ranges from 21.2° C to 30.2°C between 08:00 and 14:00.

Table 127 T6 minimum and maximum temperatures

T6 /Date	Min temp.	Max temp.
02/10/2013	N/R	N/R
03/10/2013	N/R	N/R
04/10/2013	19.9	31.8
05/10/2013	19.9	27.9
06/10/2013	20.6	29.8
07/10/2013	20.8	30.6
08/10/2013	19.9	26.6
Average	**20.22**	**29.34**

Table 127 shows temperatures taken in the classroom at the T6 from 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 19.9°C, recorded on 4 October 2013, 5 October 2013 and 8 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 31.8°C, recorded on 4 October 2013. No data was recorded on 2 October 2013 to 3 October 2013. The average for minimum and maximum temperatures for T6 from 2 October 2013 to 8 October 2013 ranges from 20.2° C to 29.3°C between 08:00 and 14:00.

Table 128 T7 minimum and maximum temperatures

T7 /Date	Min temp.	Max temp.
02/10/2013	N/R	N/R
03/10/2013	N/R	N/R
04/10/2013	19.9	30.1
05/10/2013	20.5	28.9
06/10/2013	21.3	31.3
07/10/2013	22.1	30.5
08/10/2013	20	26.8
Average	**20.76**	**29.52**

Table 128 shows temperatures taken in the classroom at the T7 from 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 19.9°C, recorded on 4 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 31.3°C,

recorded on 6 October 2013. No data was recorded on 2 October 2013 to 3 October 2013. The average for minimum and maximum temperatures for T7 from 2 October 2013 to 8 October 2013 ranges from 20.8° C to 29.5°C between 08:00 and 14:00.

Table 129 T8 minimum and maximum temperatures

T8/ Date	Min temp.	Max temp.
02/10/2013	N/R	N/R
03/10/2013	N/R	N/R
04/10/2013	N/R	N/R
05/10/2013	N/R	N/R
06/10/2013	N/R	N/R
07/10/2013	N/R	N/R
08/10/2013	N/R	N/R
Average	N/R	N/R

Table 129 shows no temperatures readings were recorded in the classroom at the T8 from 2 October 2013 to 8 October 2013 between 08:00 and 14:00, due to data logger malfunction.

Table 130 T9 minimum and maximum temperatures

T9/ Date	Min temp.	Max temp.
02/10/2013	N/R	N/R
03/10/2013	N/R	N/R
04/10/2013	20.5	29.2
05/10/2013	20.9	28.1
06/10/2013	21.7	30.4
07/10/2013	20.7	30.4
08/10/2013	21.1	27.8
Average	**20.98**	**29.18**

Table 130 shows temperatures taken in the classroom at the T9 from the 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 20.5°C, recorded on 4 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 30.4°C, recorded on 6 October 2013 and 7 October 2013. No data was recorded on 2 October 2013 to 3

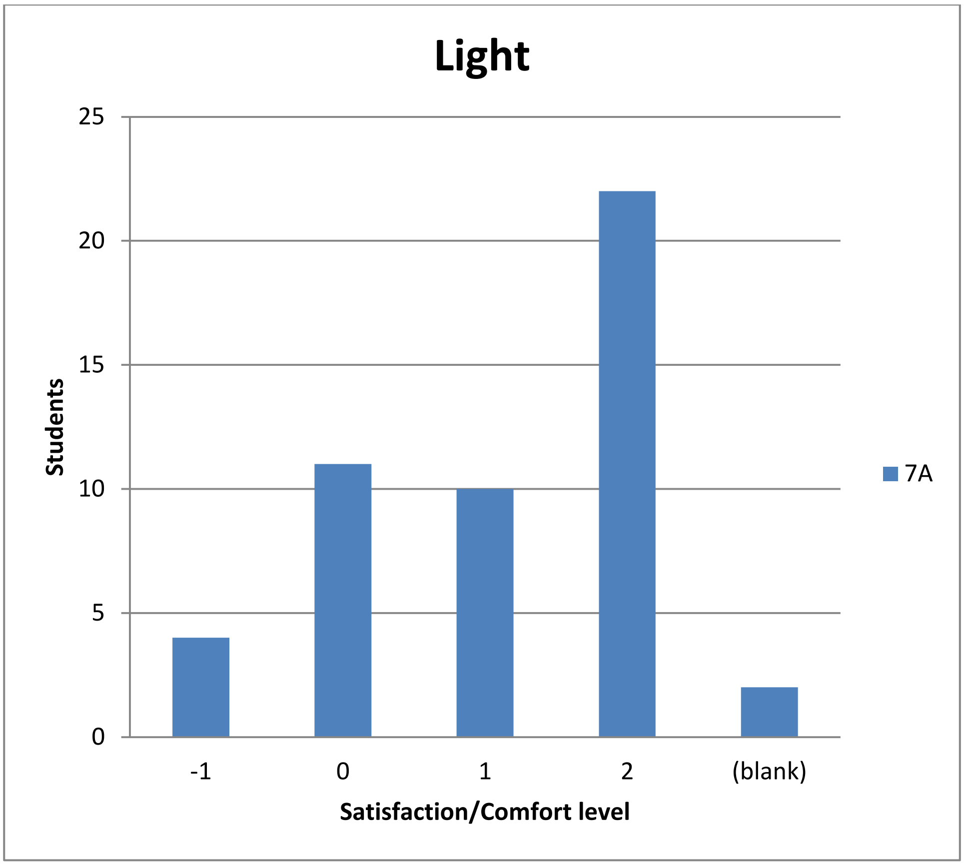
October 2013. The average for minimum and maximum temperatures for T9 from 2 October 2013 to 8 October 2013 ranges from 20.9 C to 29.2°C between 08:00 and 14:00.

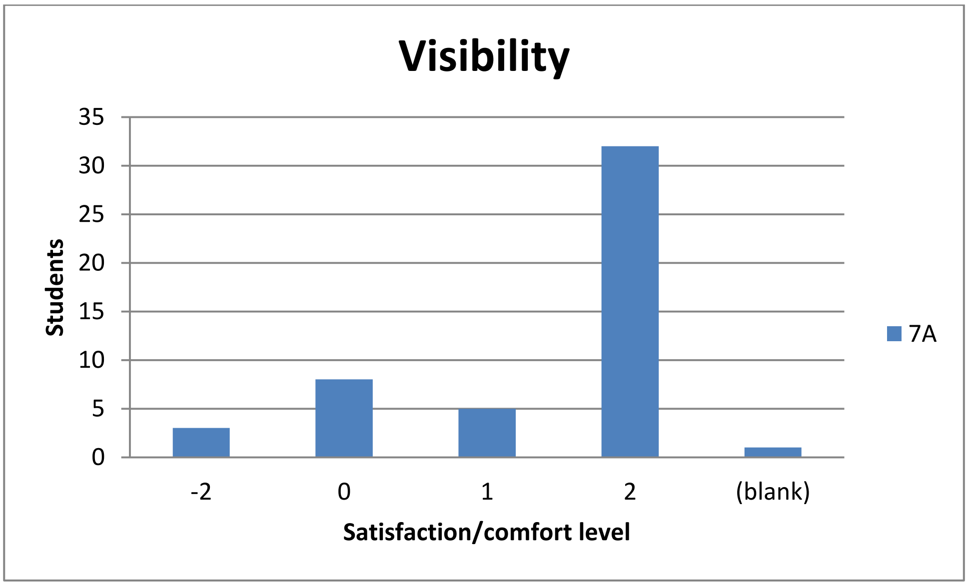
Table 131 T10 minimum and maximum temperatures

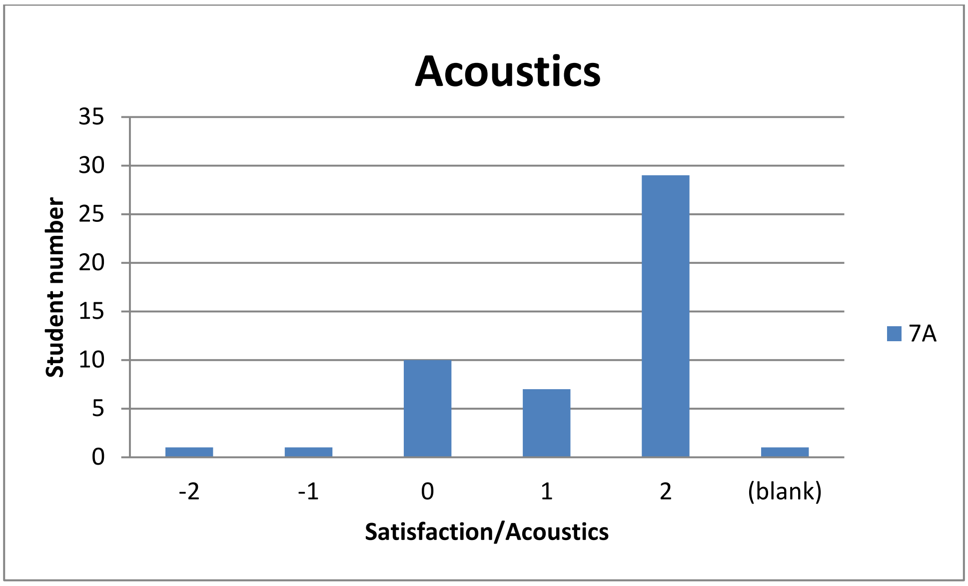
T10/ Date	Min temp.	Max temp.
02/10/2013	N/R	N/R
03/10/2013	N/R	N/R
04/10/2013	19.4	30.1
05/10/2013	19.9	27.8
06/10/2013	20.6	29.6
07/10/2013	21.2	30.9
08/10/2013	19.5	26.5
Average	**20.12**	**28.98**

Table 131 shows temperatures taken in the classroom at the T10 from 2 October 2013 to 8 October 2013 between 08:00 and 14:00. The minimum temperature (taken in the morning - 08:00) is 19.4°C, recorded on 4 October 2013. The maximum temperature (taken in the afternoon - 14:00) is 30.9°C, recorded on 7 October 2013. No data was recorded on 2 October 2013 to 3 October 2013. The average for minimum and maximum temperatures for T10 from 2 October 2013 to 8 October 2013 ranges from 20.12° C to 28.9°C between 08:00 and 14:00.

Grade 7A: Learner perception






Acoustics
Student number
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25
20
15
10
5
0
-2
-1
0
1
2
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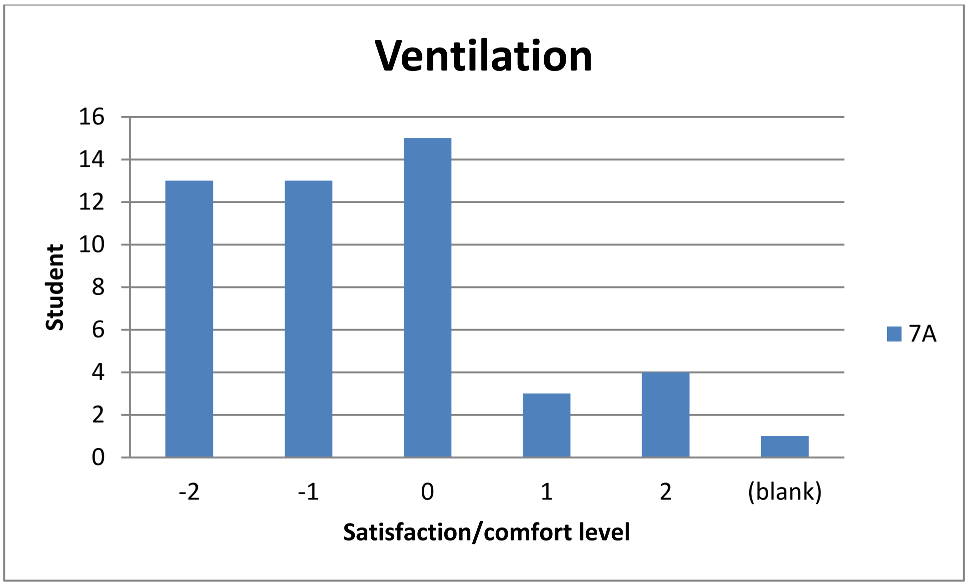
Satisfaction/Acoustics
7A


Ventilation
Student
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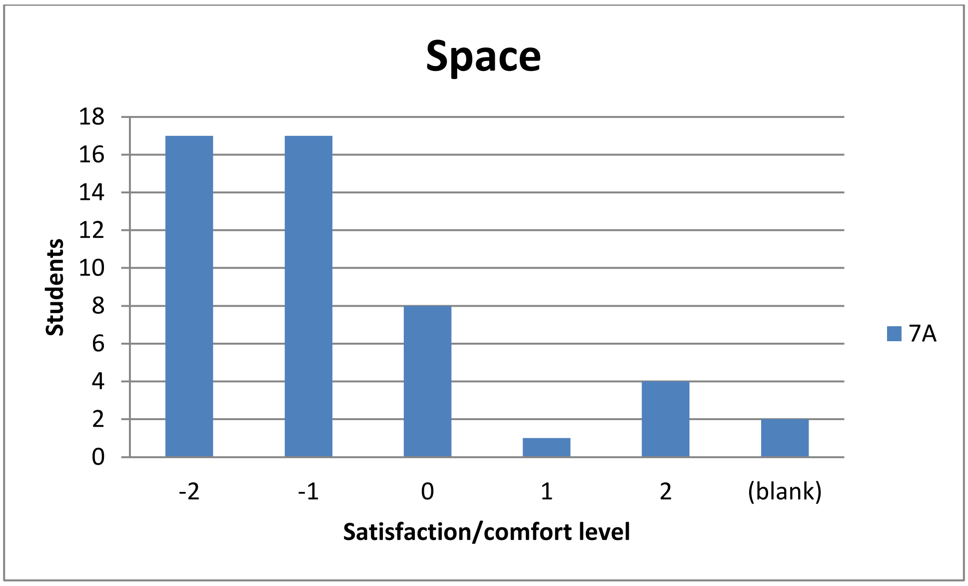
14
12
10
8
6
4
2
0
-2
-1
0
1
2
(blank)
Satisfaction/comfort level
7A


Space
Students
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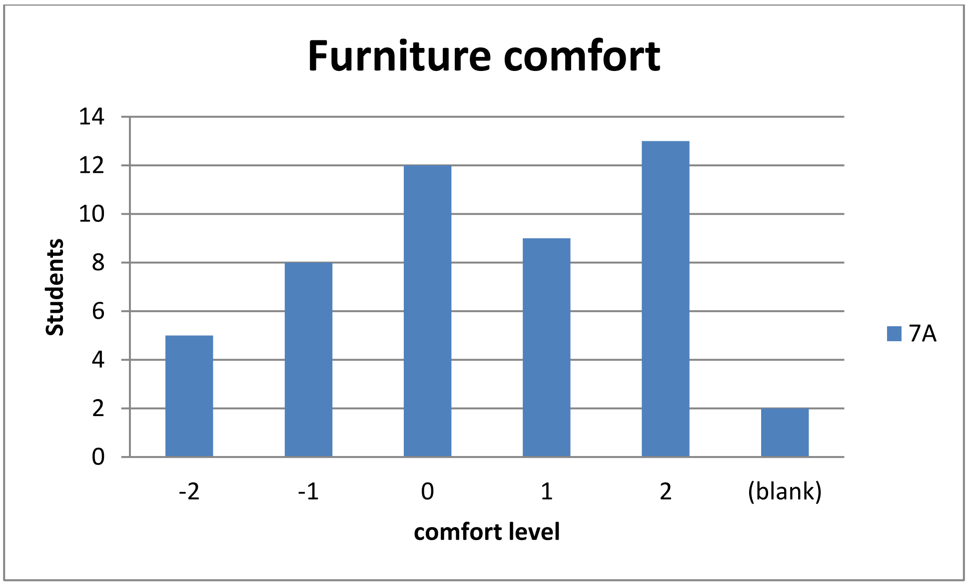
16
14
12
10
8
6
4
2
0
-2
-1
0
1
2
(blank)
Satisfaction/comfort level
7A


Furniture comfort
Students
14
12
10
8
6
4
2
0
-2
-1
0
1
2
(blank)
comfort level
7A

12 Addenda C – Examiners' report

Question 1: p.17

Do you think that comfort temperature standards that relate to the UK (CIBSE) are relevant for conditions and climate in South Africa (SA)? and why if so? And what alternatives might be preferable for defining suitable occupied temperature in SA are they not so relevant?

Acceptable summer indoor operative air temperature range for naturally ventilated school buildings is recommended not to exceed 25.0°C, and indoor operative air temperature above 28.0°C range is limited to 1% of the annual occupied period (Chartered Institution of Building Services Engineers (CIBSE) 2006).

Response:

1. **Indoor operative temperature standards:**

The CIBSE Guide A: Environmental design (2006) refers to comfort temperature in non-conditioned buildings in the following way – *"… 25 °C as an acceptable summer indoor design operative temperature for non-air conditioned office buildings (and school building), … and … limiting the expected occurrence of operative temperatures above 28 ºC to 1% of the annual occupied period (e.g. around 25–30 hours)"* (CIBSE 2006:12).

2. **The relevance of this guideline for conditions and climate in South Africa are discussed below:**

Lack of local standards

There is an absence of thermal comfort research in South Africa; therefore there is a gap in thermal comfort data that could be correlated with the availability of mean monthly temperatures to determine the South Africa's comfort/neutral temperature. Due to this deficit, South Africa does not have thermal comfort standards to refer to.

Scope

The scope of application of the guideline is relevant to non-air conditioned office buildings and school buildings. The analysis carried out by the study is on comfort in school buildings, therefore falls into the same scope.

International standards

The CIBSE guidelines are widely and internationally regarded as accepted practice by engineers or built environment professionals in the United Kingdom and abroad. The CIBSE recommendations are based on professional experience and are informed by comfort standards but reflect the assumption that for a given activity there is a given 'best temperature' and that this is correct for all circumstance (Nicol, Humpherys & Roaf 2012).

Comfortable temperature:

Researchers (Auliciems 1969 and Humphreys 1978) suggest that comfortable/neutral temperature (T_n), changes with outdoor mean monthly temperatures.

Researchers (Humphreys 1978, Griffiths 1990,Nicol & Roaf1996, De Dear, Bragger & Cooper 1997, Humphreys & Nicol 2000 and Holm & Engelbrecht 2005) have attempted to find the correlation between the temperature range that is considered comfortable and general trend in local climates.

Based on the available field survey data the above mentioned researchers found a correlation between the monthly outdoor means temperature (T_m / T_{om}) and temperatures that reported minimal discomfort (neutral/ comfort temperature T_n).The following comfort equations were derived from their studies**.**

Table 132 Comfortable temperature equations

Researchers	Comfort Equation
1. Humphreys 1978	T_n =11.9 + 0.534T_m
2. Griffiths 1990	T_n =12.1 + 0.534T_m
3. Nicol & Roaf 1996:	T_n =17 + 0.38T_m
4. De Dear, Bragger & Cooper 1997	T_n =17.8 + 0.31T_m
5. Humphreys & Nicol 2000	T_n =13.5 + 0.54T_m
6. Holm & Engelbrecht (2005)	T_nDBT =17.6+.31To_{ave}

Research on comfortable/neutral temperature (T_n) in 'free running' or non-conditioned buildings, indicates an interesting methodology to determine thermal comfort standards**.**

Alternative references for determining thermal comfort in South Africa:

Due to the little thermal comfort data in South Africa and the availability of mean monthly temperatures, comfort equations (Table 1) may offer alternatives that might be preferable for determining suitable occupied temperature in South Africa.

South Africa has six climatic zones with varying mean monthly temperatures (See table 3 & figure 1). Each climatic zone has its own cultural and architectural traditions influenced by climate. Recent study on comfortable temperature in South Africa, adopted the dry bulb-based comfort temperature (T_nDBT) equation for naturally ventilated buildings South Africa climate i.e. T_nDBT=17.6+.31To_{ave} (To_{ave} = average outdoor DBT of the day, month or year) (Holm & Engelbrecht 2005). According to with Holm & Engelbrecht (2005) the comfort temperature for the South African climate ranges from 17.8°C to 29.5°C.

If comfort equations (Table 1) were used to determine comfortable temperature for climatic zone in which the case studies are located using the mean monthly temperatures for the City of Tshwane (CoT),the calculated comfortable temperatures for City of Tshwane range for the summer months of September and October would range from 22.0°C to 24.9°C (See Table 2).

According to Szokolay (2004) the range for acceptable comfort conditions (comfort zone) can be taken ±2.5 above and below neutral/comfort temperature (T_{n}). Therefore, comfortable temperature for summer in the case studies school buildings in City of Tshwane is assumed to range from 19.5°C - 27.4°C.

Table 133 Calculated thermal comfort for City of Tshwane

Researchers	Comfort Equation	If Mean monthly temp. (T_m) =	
		19°C (Sep)	21°C (Oct)
1. Humphreys 1978	T_n =11.9 + 0.534T_m	T_n = 22.0	T_n =23.1
2. Griffiths 1990	T_n =12.1 + 0.534T_m	T_n =22.3	T_n =23.3
3. Nicol & Roaf 1996	T_n =17 + 0.38T_m	T_n =24.2	T_n =24.9
4. De Dear, Bragger & Cooper 1997	T_n =17.8 + 0.31T_m	T_n =23.7	T_n =24.3
5. Humphreys & Nicol 2000	T_n =13.5 + 0.54T_m	T_n =23.7	T_n = 24.8
6. Holm & Engelbrecht (2005)	T_nDBT=17.6+.31To_{ave}	Holm & Engelbrecht (2005)	T_nDBT =24.8

Conclusion

The research carried out in the thesis show that learners were comfortable within temperature ranges that were higher than those recommended by the CIBSE guideline. CIBSE guideline is however relevant.

Table 134 Climatic zones

Zone	Description	Major centre
1	Cold interior	Johannesburg, Bloemfontein
2	Temperate interior	COT/Pretoria, Polokwane
3	Hot interior	Makhado, Nelspruit
4	Temperate coastal	Cape Town, Port Elizabeth
5	Sub-tropical	coastal East London, Durban, Richards Bay
6	Arid interior	Upington, Kimberley

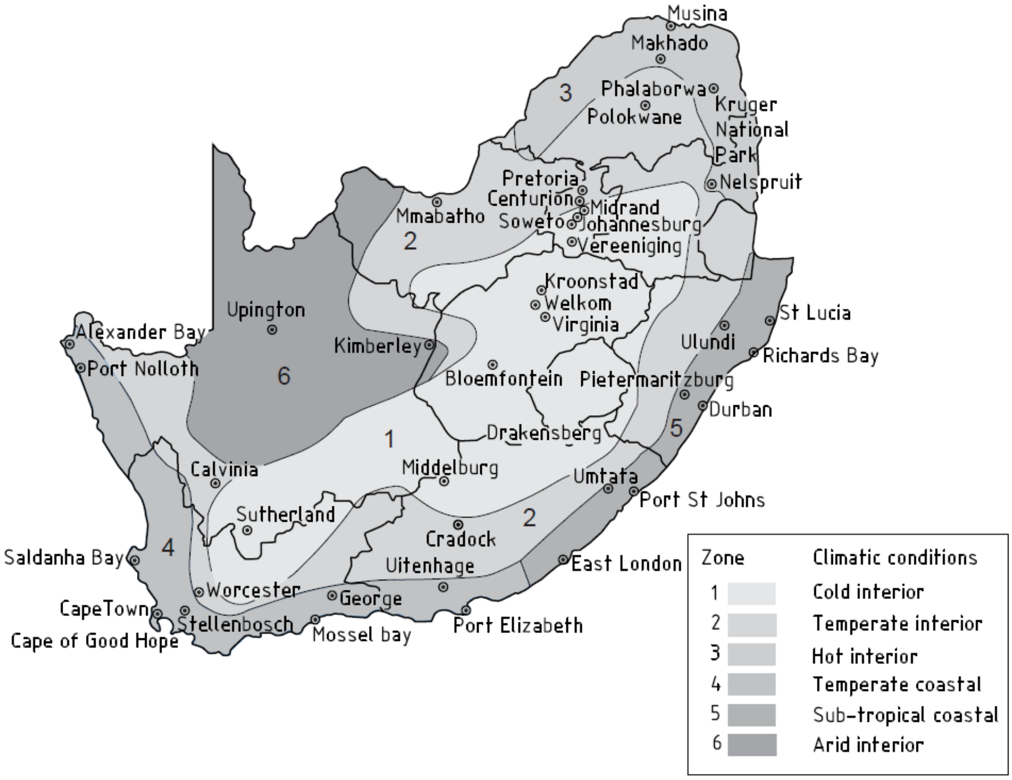


Figure 50 South Africa's climatic zones (SANS 10400:XA)

Question 2: p.20

It is mentioned that the Bill of Rights states that everyone has the right to an environment that promotes 'health and well-being'. This is a political aspiration (in a country where morally questionable early work on extreme thermal discomfort was done in the very deep mines of the region) but do you think that it is all feasible that a standard – e.g. ASHRAE 55 could provide a robust method with which to define what 'health and well-being' might mean in your context and thus make it enforceable?

The Bill of rights Section 24(a) in the South African constitution, states that everyone has the right to an environment that promotes health and wellbeing.

Response:

The South African Constitution (Act of 1996) Bill of rights (Section 24(a)) states that "*Everyone has the right to an environment that is not harmful to their health or well-being*" putting the environmental rights into the context of human health.

For the South African built environment to promote 'health and well-being', built environment legislation such as the Building Regulation and the Occupational Health and Safely Act have to be enforced.

A standard will provide reliable, uniform and safe methods that can be used for assessing if the environment meets recommended benchmarks. A standard will not legally enforce that the occupants maintain the environment to be healthy.

My view is that the a standard such as the ASHRAE 55 can recommend a method to assess and define what is thermally acceptable for the attainment of environments that are conducive to health and well-being of building occupants. A standard of such stature will not be enforceable but will recommend what is acceptable internationally.

Question 3: p.87

Do you think that the concepts drawn from the standards better to comfort in a) US type air-conditioned environment or b) 'breezy' naturally ventilated SA schools? Or to both?

Issue iii:
The development of Learner Thermal Comfort Protocol (LTCP) requires concepts to be drawn from the thermal comfort standards, then adapted and adopted for them to be applied in classroom environments.

The concepts drawn from thermal comfort standards are:

viii. **The occupied zone**
ix. **Radiant asymmetry**
x. **Vertical air temperature difference**
xi. **Thermal insulation of clothing**
xii. **Activity**
xiii. **7 point scale thermal sensation scale**
xiv. **Adaptive thermal comfort chart/model**

Response:

The application of ASHRAE 55 Standard in both conditioned and non-conditioned spaces and buildings requires the following:

1) Specification of space to which the standard is to be applied;
2) Identification of occupants;
3) Identification of occupants activity and;
4) Identification of occupants clothing insulation value.

These requirements are included as concepts in the development of Learner Thermal Comfort Protocol (LTCP), i.e. item i, iv and v (Issue iii).

The concepts that are selected for application in both conditioned and non-conditioned space are radiant asymmetry, vertical temperature difference and the 7 point scale thermal sensation scale. The adaptive thermal comfort chart/model can only be used in non-conditioned space.

The concepts are explained as follows:

i. **The occupied zone** is the location where the temperature measurements are recorded. The occupied zone is sufficiently away from areas where extreme values of the thermal parameters are estimated, i.e. near the window, entry points, corners, fans, radiators, etc.

ii. ***Radiant asymmetry and Vertical air temperature difference*** result in local thermal discomfort. Local thermal discomfort is defined as unwanted cooling or heating on the whole body of one particular part of the body.
Radiant asymmetry is caused by warm ceilings, cool or warm walls and direct sunlight. People are more sensitive to asymmetric radiation caused by a warm ceiling than hot or cold vertical surfaces.
Vertical air temperature difference is caused when air temperature is warmer at the head than at the ankle.

iii. ***Clothing thermal insulation*** is the amount of clothing thermal insulation has an impact on thermal comfort.
iv. ***Activity*** is the type of activity that one is engaged in,it has an impact on thermal comfort.
v. ***7 point scale thermal sensation scale*** is used to measure occupants thermal perception
vi. ***Adaptive thermal comfort chart/model*** is used in non-conditioned spaces, to assess thermal comfort acceptability. It requires indoor and external temperature to assess acceptability.

My view is that concepts drawn from the standards can be used for both conditioned and non-conditioned school, except the adaptive thermal comfort model, which is applied only to non-conditioned school only.

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