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Using an inappropriate thermal benchmark leads to overheating in UK primary schools

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Abstract:

Schools' buildings can have a significant impact on students and teachers' health and performance through their internal environment such as noise level, indoor temperature, air quality and light. Providing good environmental conditions for schools has always been critical. The two main reasons are: firstly of the conflict between comfort factors (thermal, lighting, acoustic comfort and air quality) as they are interrelated and secondly the use of relaxed thermal, air quality, acoustic and lighting benchmarks. In this study, the current thermal benchmark, which is used to design and refurbish the UK school classrooms, is assessed in order to evaluate the extent to which it is lenient and whether it represents the occupants' feelings.

Keywords: Overheating, School classrooms, Fixed thermal benchmark, Adaptive thermal benchmark

1. Introduction:

School buildings can have a significant impact on students and teachers' health and performance through their internal environment such as noise level, indoor temperature, air quality and light. According to Heath et al. (2000), there has always been concern regarding the indoor environment of schools due to shortage of funding for school buildings, because poor environments have a greater impact on children than on adults, and because the length of time that children spend at school is higher than the time they spend at home. For this reason, considerations of environmental and comfort factors have always had a specific position in any building design guidelines. Despite this, schools have failed to provide optimum environmental conditions from the Victorian era up until now.

The summary of conflict between comfort factors in each era is reviewed in the Background section. The conflict between comfort factors can be one of the main reasons for poor environmental conditions in school classrooms as a result of the lack of designer concentration in the first stages of design. The other reason for poor environmental conditions may be due to use of the lenient benchmarks which is the topic of this study.

In this study, the current thermal benchmark, which is used to design and refurbish the UK school classrooms, is assessed in order to evaluate the extent to which it is too lenient and whether it adequately represents the occupants' feelings. It should be noted that the schools which were built during different periods are still being utilised in London. For this reason, a range of schools from Victorian to modern have been examined.

2. Background:

The background study is carried out in two parts. The first part concentrates on the conflicts which are observed in schools built in different priods in the UK, and the second part concentres on different overheating benchmarks.

2.1. Conflict between comfort factors

As far as the comfort factors requirements are concerned, the history of the UK school construction is divided into five time periods the Victorian, Open air, Post World War II, Post-oil crisis and PCP (Primary Capital Programme) / BSF (Building School for Future) schemes. It should be noted that the schools which were built during the different periods mentioned above are still being utilised in London. In each era of school construction, there are various kinds of conflict between comfort factors. In the following list different types of conflict between comforts factors in each period are summarised:

a. Victorian schools mainly refer to the schools that were built before 1920 with heavy thermal mass material (Châtelet, n.d). On the one hand, Victorian schools have the privilege of having stack ventilation due to sash windows and high ceilings and consequently the ability to maintain indoor air quality and thermal comfort during summer. On the other hand, the occupants of these schools suffer from high reverberation times and consequently a higher level of noise due to their high ceilings. As a result, the type of conflict that is observed in Victorian schools is the conflict between acoustic comfort and 'air quality/ thermal comfort' in summer.

b. Open air schools mainly refer to the schools built in the early part of the 20th century, when there was concern over the spread of tuberculosis. These schools at the time of their construction were thermally comfortable during summer but not winter. These schools had the benefit of cross ventilation, as large windows and doors could be fully opened to maintain indoor temperature and to remove excessive heat during cooling seasons (summer). Although these schools had the benefit of a high level luminance, good level of natural light and thermal comfort during summer, a large amount of heat was lost during winter due to their large openings. As a result, the type of conflict observed in open air schools is, the conflict between 'thermal comfort' and 'lighting comfort' in winter and also, the conflict between thermal comfort in winter and summer. These schools were modified by covering up one side of the classrooms using glass enclosure in order to improve environmental conditions. With this modification, classrooms have had a lower risk of heat loss during winter; however, they have had a higher risk of experiencing overheating during summer as the benefit of cross ventilation was reduced to a single sided ventilation (conflict between thermal comfort in winter and summer).

c. Post-war schools mainly refer to the schools built as a result of the baby boom after the destruction caused by World War II and the growing need for the schools at the beginning of fifties (1945 -1970) [Woolner, 2010]. On the one hand, the post-war classroom had a high level of natural light due to the large windows but, on the other hand, these classrooms produce excessive glare and receive a high amount of solar gain that causes overheating during summer and cold due to heat loss during winter.

This is the conflict between lighting level and thermal comfort in post war primary school classrooms. It should be noted that the poor thermal comfort is not only related to the large windows but also to the lightweight construction materials used in these buildings.

d. Post- oil crisis schools refer to the schools that are constructed due to two phenomena i.e. the energy crisis in the 1970s and the sick building syndrome. As a result, the open-plan space school concept was introduced in the United State, in 1970 and the idea spread to Europe and especially to the UK (Bennet et al, 1980). Open-plan schools had the privilege of having cross ventilation to maintain classrooms' indoor temperature and air quality during summer but they were highly noisy and were not acoustically comfortable. As a result, there was a conflict between acoustic comfort and 'thermal comfort / air quality' in these kinds of schools. Therefore, the open plan classrooms were converted to cellular classrooms to overcome the acoustic problem. As a result of this conversion, classrooms lost their opportunity for having cross ventilation in summer (Conflict between acoustic comfort and 'thermal comfort and air quality').

e. BSF & PCP schools mainly refer to the schools built under the Primary Capital Programme (PCP) and Building Schools for the Future (BSF) schemes which were announced for primary and secondary schools in 2003 & 2006 respectively. The PCP and BSF programmes were the first wave of school construction / refurbishment since the huge Victorian and post-war building programmes. Although the main principle of constructing these schools is to provide comfortable environments, these schools still fail to provide comfortable environment in some cases due to the conflict between comfort factors. Mumvic et al. (2009) study the winter indoor air quality, thermal comfort and acoustic performance of a newly built secondary school in England following BSF investment. Based on this research, complex interactions between thermal comfort, ventilation and acoustic comfort are studied. Two types of conflict are shown in the research. Firstly, conflict between acoustic comfort and air quality: Schools in this research are equipped with mechanical ventilation to maintain indoor air quality. The noise level measured inside the classrooms when occupants were engaged with a quiet test exceeded 50dB (A), which is far above the requirement proposed by BB93. This is a result of the noise produced by the mechanical ventilation. This shows one kind of conflict between air quality and acoustic comfort. Secondly, conflict between air quality and thermal comfort: the mechanical ventilation installed to provide good air quality, in this situation should provide 8 l/s per person fresh air but produces cold droughts that have a negative impact on thermal comfort. Hence it can be seen that although the school has recently been built based on the BSF programme, it does not provide a comfortable environment as the comfort factors conflict and interact with each other.

As explained above, each type of school has its own type of conflict between comfort factors that lead classrooms to experience poor environmental condition, Another type of conflict that is investigated by Montazami et al. (2011) is the conflict between acoustic comfort and 'thermal comfort / air quality' in the schools located around Heathrow Airport. This conflict is not limited to a particular era and occurs in any naturally ventilated school which is located under the Heathrow Airport flight path. Based on this research, it is observed that the occupants of schools which are located under Heathrow Airport Flight path keep the windows shut in order to provide acoustic comfort while they lose their chance to have natural ventilation. This leads the classroom to suffer from overheating and poor air quality.

As is observed, one of the main reasons of poor environmental conditions is due to the conflict between comfort factors. The other reason may be due to the use of relaxed comfort benchmarks which is the topic of this study. For this reason, in the next part, a complete literature review is carried out regarding the overheating guidelines which have been in place for a number of years.

2.2. Overheating guidelines for UK classroom

Generally, the overheating guidelines follow one of the two adopted approaches: Adaptive and Fixed.

2.2.1. Fixed approach: The fixed approach is the most popular approach. This approach considers a fixed temperature as a benchmark (comfort temperature) for evaluating overheating in a classroom. The three guidelines that are designed based on the fixed approach are BB87, BB101 and CIBSE that help a designer to assess the overheating occurrence in the UK classroom. Each of these guidelines is explained in detail further below.

2.2.2. Adaptive approach: The adaptive approach is the most recent approach. This approach considers an adaptive temperature as a benchmark (the comfort temperature which can be calculated) for evaluating overheating in a classroom. Based on this approach, temperatures at which the majority of people are comfortable vary with the running-mean of the external temperature which can be calculated. The two guidelines which are designed based on the adaptive approach are the BS guideline which helps a designer to assess the maximum allowable difference from the adaptive comfort temperature and the Nicol guideline that helps to identify the percentage of occupants who suffer from overheating.

In the followings, the guidelines which are designed based fixed and adaptive models are explained in detail:

Fixed model guidelines:

a. **BB87:** According to Building Bulletin 87 (BB87) which was published in 2003 for UK school building, a classroom is defined as overheated when the internal air temperature exceeds 28°C. The guideline allows flexibility of up to 80 occupied hours in a year above this temperature, normally in the non-heating periods of May to September excluding August.

b. **BB101:** These overheating criteria will ensure that the design of future schools is not dictated by a single factor, unlike BB87, but by a combination of factors that will allow a degree of flexibility in the design of the school. These criteria are only applicable for the cooling season for the occupied period (i.e. 9:00-15:30, Monday to Friday from 1st May to 30th September excluding August which is school summer holiday). These criteria are in compliance with Approved Document L2 for summertime overheating for teaching and learning areas and are as follows:

   - There should be no more than 120 hours when the air temperature in the classroom rises above 28°C.

- The average internal to external temperature difference should not exceed 5°C (i.e. the internal air temperature should be no more than 5°C above the external air temperature on an average).
- The internal air temperature when the space is occupied should not exceed 32°C. In order to show that the proposed school will not suffer overheating two of these three criteria must be met.

c. **CIBSE:** Two temperature thresholds have been defined by CIBSE for schools: a lower temperature threshold, which is taken to indicate when occupants will start to feel 'warm' (above 25°C) and higher threshold temperature, which is taken to indicate when occupants will start to feel 'hot' (above 28°C). However, to define a fixed measure of 'overheating' an excess of more than 1% of occupied hours in a year over the higher temperature benchmark is adapted to indicate a failure of the building to control overheating risk (CIBSE Guide A, 2006).

   The formation of an overheating taskforce by CIBSE is in part a recognition that there are problems with the use of a fixed, nationwide threshold temperature and 'hours over' criterion, which are as follows :

   - According to Humphreys and Nicol (Nicol et al, 2009), comfort temperature varies in accordance to outdoor running mean temperature and therefore is not fixed.
   - The CIBSE criteria fail to recognise the severity of overheating which is as important as its occurrence (Nicol et al, 2009).
   - Two criteria were developed by CEN Technical committees in BS EN15251 which considers both discomfort occurrence and severity: cooling degree-hours measure and a weighted measure based on Predicted Percentage Dissatisfaction (PPD). However, the PPD has been argued to be an unreliable indicator in naturally ventilated buildings according to Humphrey and Nichol (Nicol et al, 2009).
   - As overheating evaluation for buildings is based on a fixed threshold depending on the number of occupied hours above threshold, therefore by changing the number of occupied hours, the result can be altered to solve the overheating problem, which is totally unrealistic (Nicol et al, 2009) and deceptive.
   - Based on the fixed temperature threshold, it is debateable whether overheating should be measured over a whole year or a shorter period during a year (Nicol et al, 2009). For example, based on the CIBSE overheating is measured over a whole year and based on BB101 and BB87, it is measured on the duration of cooling seasons (May to September excluding August).

For all above reasons, some other criteria based on adaptive model are presented.

Adaptive model guidelines:

a. British Standard: Alternative criteria are presented by British Standard (based on survey of thermal comfort in European buildings and first proposed in CIBSE Guide A (Nicol et al, 2009) for thermal comfort in naturally ventilated building using an adaptive thermal comfort model.

According to these criteria, thermal comfort is not a fixed temperature and varies according to recent climate conditions (e.g. over selected previous days). The criteria link comfort temperature to ‘running mean temperature’ (Trm). The running mean is calculated from the external temperature over the preceding days, with a weighting taking into account the greater influence of the most recent day, using the formula below where the mean outdoor temperature exceeds 10°C.

$$Tc=0.33Trm + 18.8 \quad (1)$$

The following graph (Graph 3-1.3) shows the comfort temperatures as a function of outdoor temperature (from CIBSE 2006 cited in Nicol et al, 2009):

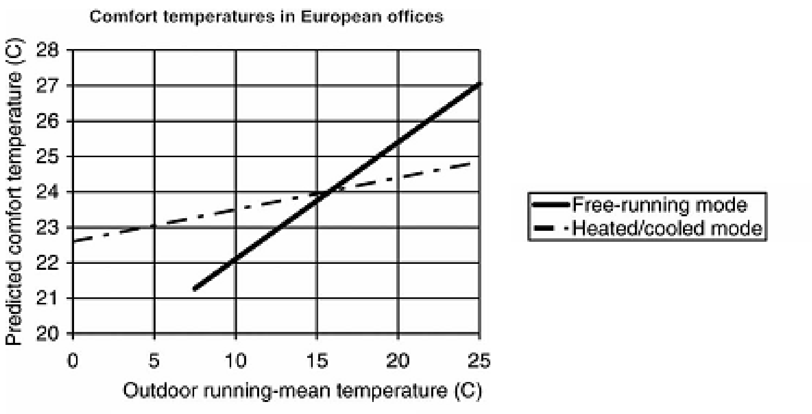

Figure 1: Comfort temperature as a function of outdoor running means temperature (CIBSE, 2006)

British Standard proposes that there is a maximum allowable difference from comfort temperature as it is shown in the following table (Table 1).

Category	Explanation	Suggested accaptable range
I	High level of expectation only used for spaces occupied by very sensitive and fragile persons	±2K
II	Normal expectation (for new buildings and renovations)	±3K
III	Moderate expectation (used for existing buildings)	±4K
IV	Values outside the criteria for the above categories (only acceptable for a limited periods)	
Source: British Standards (BSI) (2007e).		

Table 1: Suggested applicability of the categories and their associated acceptable temperature range. (British Standard 2007)

b. **Percentage of discomfort by occupants:** Nicol and Humphreys (cited in Nicol et al, 2009) suggest that occupants’ discomfort is related to ΔT by applying a weighting factor which reflects the non-linear relationship between heat discomfort (percentage of overheating by occupant) and departure from the comfort temperature which is observable in the following graph (Figure 2). The percentage of discomfort is be calculated from the following formula (equation 2):

$$P = \frac{e^{(0.4734*\Delta T-2.607)}}{\{1 + e^{(0.4734*\Delta T-2.607)}\}}$$

In the above formula, ΔT refers to the differences between actual temperature and ‘Tc=adaptive thermal comfort’. Tc is related to ‘the outdoor running mean temperature’ and calculated from the equation Tc=0.33Trm+18.8. ‘Trm’ refers to the thermal running mean temperature and CEN Standard EN15251 (2009) gives an approximate calculation method (for Trm) using the mean temperature for the last 7 days ($\alpha = 0.8$).

$$\underline{Trm = (Tod -1 + 0.8\ Tod -2 + 0.6\ Tod -3 + 0.5\ Tod -4 + 0.4\ Tod -5 + 0.3\ Tod -6 + 0.2\ Tod -7)/3.8} \quad (3)$$

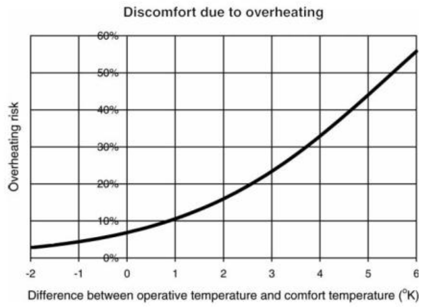

Figure 2: The proportion of subjects voting warm or hot on the ASHRAE scale as a function of the difference between the indoor operative temperature and CEN comfort temperature, (Nicol et al)

This alternative criterion proposed by British Standard and developed by Nicol regarding the percentage of overheating by occupants is only valid for spaces engaged in mainly sedentary activities such as offices, classroom etc (Nicol et al, 2009).

3. Methodology:

This research is carried out objectively and subjectively. All the objective and subjective data are recorded by the author. In the objective survey, indoor temperatures of 139 classrooms from 18 naturally ventilated primary schools in London were recorded every half hour by placing two miniature temperature data loggers called 'I Buttons' in each classroom in June and July of the years 2005, 2007 and 2008 with the accuracy of 0.5 ° C in each classroom. The indoor temperatures were recorded for both occupied and unoccupied durations. In the UK Primary Schools, children attend school from Monday to Friday between 0900 to 1530 hours. The occupied indoor temperature mentioned in this text refers to the recorded temperatures of these classrooms over these durations. Graph 3 shows the average percentage distribution of indoor temperature in all schools in 2005, 2007 and 2008.

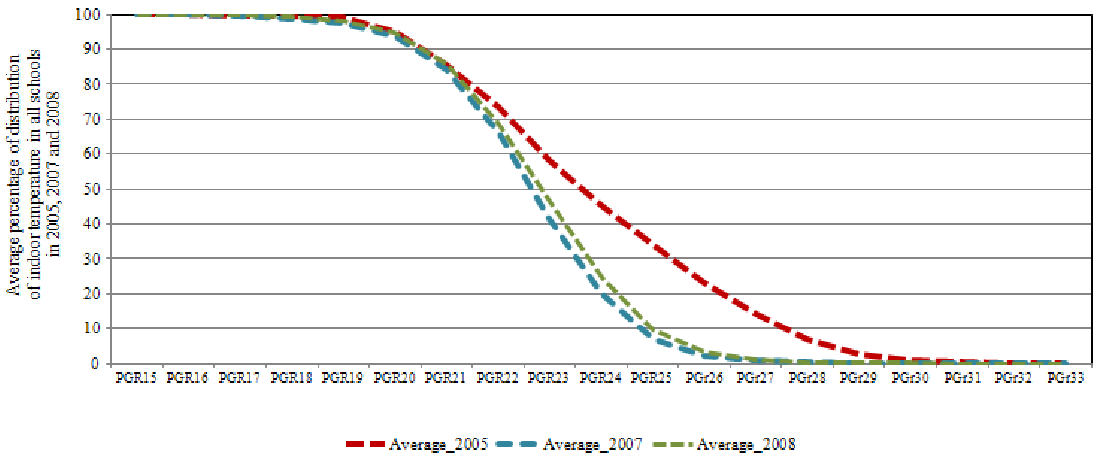

Figure 3: Average percentage distribution of indoor temperature in all schools in 2005, 2007 and 2008.

One of the climate factors that have an impact on indoor temperature is outside temperature. For this reason, the outdoor temperatures were collected from the Weather Underground Website (2008) which shows the outdoor temperatures in half hourly intervals. The Heathrow Station was chosen for outdoor temperature. The outdoor temperatures were collected from this website for June and July of 2005, 2007 and 2008. Daily outdoor temperatures for the duration of study are summarised in figures 4 and 5.

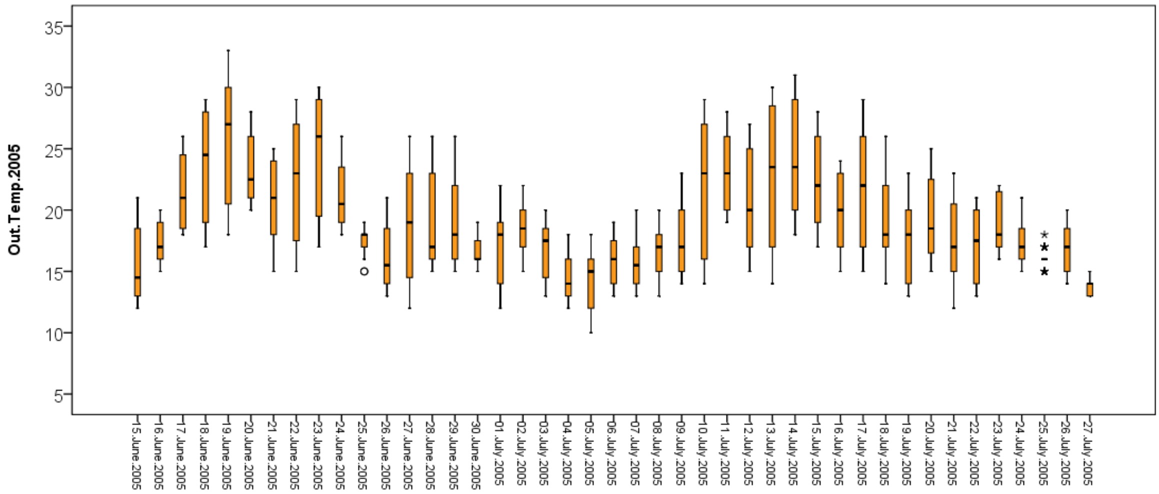

Figure 4: Daily Outdoor temperature in June and July 2005

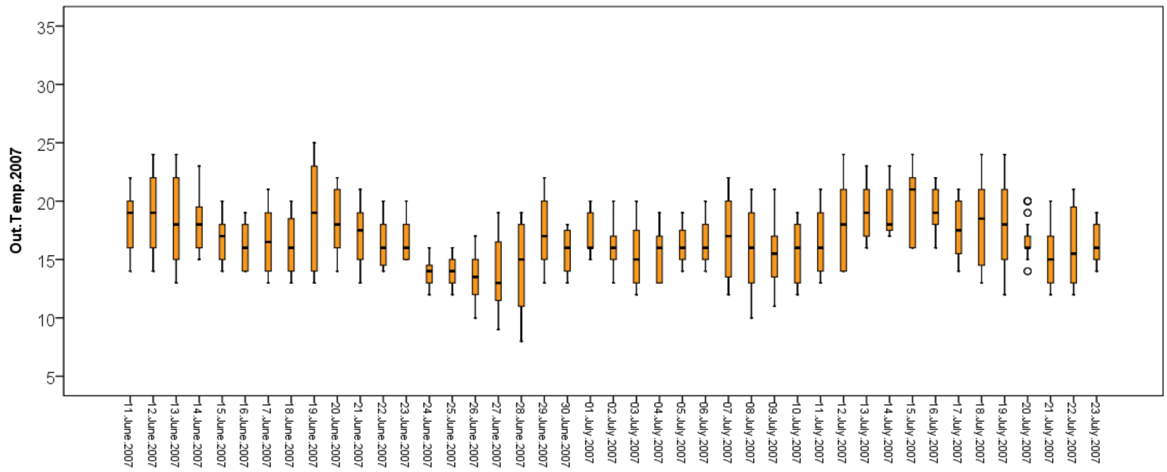

Figure 5: Daily Outdoor temperature in June and July 2007

In the subjective survey, teachers were asked to rate the level of thermal comfort inside classrooms. It was not possible to carry out the survey on large number of students and also the primary school students did not have sufficient knowledge to fill out questionnaires. Therefore, teachers were briefed so that they ensured the questionnaires reflected students’ perception of thermal comfort as opposed to own their opinion. Ninety two questionnaires were filled out by the teachers of 15 naturally ventilated schools in June and July of 2007 and 2008.

Thermal comfort	Uncomfortable	1	2	3	4	5	6	7	Comfortable

This part of the study is carried out in three stages in order to identify the most reliable overheating models. For this reason, firstly the current UK design guidelines for thermal comfort are compared with each other using real data (indoor temperature data) that have been collected from schools. Secondly, the relation between occupants' perception regarding thermal comfort are compared with the adaptive and fixed thermal comfort. Finally, the percentage of dissatisfaction from overheating is calculated for each school as one of the most reliable tools to assess overheating.

4. Analysis and discussion of results:

4.1. Stage one: Comparing the current UK design guidelines for thermal comfort with each other.

In this part, a comparison is carried out between the fixed overheating models which are proposed by Building Bulletin (i.e. BB101& BB87) and Charted Institution of Building Services Engineers (CIBSE).

In order to compare different overheating models with each other, the risk of classrooms from various schools being overheated according to fixed models (i.e.BB87, BB101 and CIBSE) are calculated for the duration of the study (Table 3). The following tables (Table 2) show the duration of studies in 2005, 2007 & 2008. The number of occupied hours within these durations are 202 hours for each year.

2008							
	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Jun	9	10	11	12	13	14	15
Jun	16	17	18	19	20	21	22
Jun	23	24	25	26	27	28	29
July	30	1	2	3	4	5	6
July	7	8	9	10	11	12	13
July	14	15	16	17	18	19	20
July	21						

2007							
	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Jun	11	12	13	14	15	16	17
Jun	18	19	20	21	22	23	24
Jun	25	26	27	28	29	30	1
July	2	3	4	5	6	7	8
July	9	10	11	12	13	14	15
July	16	17	18	19	20	21	22
July	23						

2005							
	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Jun	15	16	17	18	19	20	21
Jun	22	23	24	25	26	27	28
Jun	29	30	1	2	3	4	5
July	6	7	8	9	10	11	12
July	13	14	15	16	17	18	19
July	20	21	22	23	24	25	26
July	27						

Table 2: Duration of study in year 2005, 2007 & 2008

Table 3 shows the risk of classrooms from various schools being overheated according to different fixed models. As can be seen from this table, none of the classrooms are overheated based on BB101. Overheating experiences vary according to BB87 and CIBSE. As can be seen from Table 3, in the years of 2007 and 2008, only 'one out of seventeen' school is overheated when evaluated on CIBSE and none, when evaluated on BB87 and BB101; In 2005, 'six out of eight' schools were overheated when evaluated based on CIBSE and 'one out of eight' when evaluated based on BB87 and none based on BB101.

Year	School's Name	Hounslow				Wellington			Cranford			Grove Road							
2008	Classroom's Name	8.1	8.2	8.3	8.4	8.1	8.2	8.3	8.1	8.2	8.3	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8
	Overheating occurance based on CIBSE	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated
	Overheating occurance based on BB87	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated
	Overheating occurance based on BB 101	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated
2007	Classroom's Name	7.1	7.2	7.3	7.4	7.1	7.2	7.3	7.1	7.2	7.3	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8
	Overheating occurance based on CIBSE	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated
	Overheating occurance based on BB87	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated
	Overheating occurance based on BB 101	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated
2005	Classroom's Name	5.1	5.2	5.3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Overheating occurance based on CIBSE	Overheated	Overheated	Overheated	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Overheating occurance based on BB87	Overheated	Non overheated	Non overheated	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Overheating occurance based on BB 101	Non overheated	Non overheated	Non overheated	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Year	School's Name	Andrew					STMM				Heston			Rosary			Feltham		
2008	Classroom's Name	8.1	8.2	8.3	8.4	8.5	8.1	8.2	8.3	8.4	8.1	8.2	8.3	8.1	8.2	8.3	8.1	8.2	8.3
	Overheating occurance based on CIBSE	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	–	Non overheated	Non overheated	Non overheated	Non overheated	Overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated
	Overheating occurance based on BB87	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	–	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated
	Overheating occurance based on BB 101	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	–	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated
2007	Classroom's Name	7.1	7.2	7.3	7.4	7.5	7.1	7.2	7.3	7.4	7.1	7.2	7.3	7.1	7.2	7.3	7.1	7.2	7.3
	Overheating occurance based on CIBSE	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated
	Overheating occurance based on BB87	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated
	Overheating occurance based on BB 101	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated
2005	Classroom's Name	5.1	5.2	5.3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Overheating occurance based on CIBSE	Overheated	Overheated	Non overheated	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Overheating occurance based on BB87	Non overheated	Non overheated	Non overheated	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Overheating occurance based on BB 101	Non overheated	Non overheated	Non overheated	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Year	School's Name	Pools			Ambler			Norwood			Lady			Hungerford						
2008	Classroom's Name	8.1	8.2	8.3	8.1	8.2	8.3	8.1	8.2	8.3	8.1	8.2	8.3	8.1	8.2	8.3	8.4	8.5	8.6	8.7
	Overheating occurance based on CIBSE	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated
	Overheating occurance based on BB87	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated
	Overheating occurance based on BB 101	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated
2007	Classroom's Name	7.1	7.2	7.3	7.1	7.2	7.3	7.1	7.2	7.3	7.1	7.2	7.3	7.1	7.2	7.3	–	–	–	–
	Overheating occurance based on CIBSE	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	–	–	–	–
	Overheating occurance based on BB87	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	–	–	–	–
	Overheating occurance based on BB 101	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	–	–	–	–
2005	Classroom's Name	5.1	5.2	5.3	5.1	5.2	5.3	–	–	–	–	–	–	5.1	5.2	5.3	–	–	–	–
	Overheating occurance based on CIBSE	Non overheated	Non overheated	Overheated	Non overheated	Non overheated	Overheated	–	–	–	–	–	–	Overheated	Non overheated	Non overheated	–	–	–	–
	Overheating occurance based on BB87	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	–	–	–	–	–	–	Non overheated	Non overheated	Non overheated	–	–	–	–
	Overheating occurance based on BB 101	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	–	–	–	–	–	–	Non overheated	Non overheated	Non overheated	–	–	–	–

Year	School's Name	Colerain			Orchard		St.Gildas				Green church			
2008	Classroom's Name	8.1	8.2	8.3	8.2	–	–	–	–	–	–	–	–	–
	Overheating occurance based on CIBSE	Non overheated	Non overheated	Non overheated	Non overheated	–	–	–	–	–	–	–	–	–
	Overheating occurance based on BB87	Non overheated	Non overheated	Non overheated	Non overheated	–	–	–	–	–		–	–	–
	Overheating occurance based on BB 101	Non overheated	Non overheated	Non overheated	Non overheated	–	–	–	–	–	–	–	–	–
2007	Classroom's Name	7.1	7.2	7.3	7.1	7.2	–	–	–	–	–	–	–	–
	Overheating occurance based on CIBSE	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	–	–	–	–	–	–	–	–
	Overheating occurance based on BB87	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	–	–	–	–	–	–	–	–
	Overheating occurance based on BB 101	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	–	–	–	–	–	–	–	–
2005	Classroom's Name	5.1	5.2	5.3	–	–	5.1	5.2	5.3	5.4	5.1	5.2	5.3	5.4
	Overheating occurance based on CIBSE	Overheated	Non overheated	Overheated	–	–	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Overheated	Overheated
	Overheating occurance based on BB87	Non overheated	Non overheated	Non overheated	–	–	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated
	Overheating occurance based on BB 101	Non overheated	Non overheated	Non overheated	–	–	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated	Non overheated

Color code			
Overheated classroom	(red)	Non overheated classroom	(blue)
Missing data	–		

Table 3: Study of the classrooms' indoor temperature based on Fixed models in various schools

The cold summer of 2007and 2008 (when compared with 2005) was the reason for a big gap between occurrence of overheating in 2005 and 2007/2008. Figure 6 shows the average of mean and maximum outside temperature during the months of June and July for the last ten years. As can be seen, 2008 and 2007 were the coldest summers.

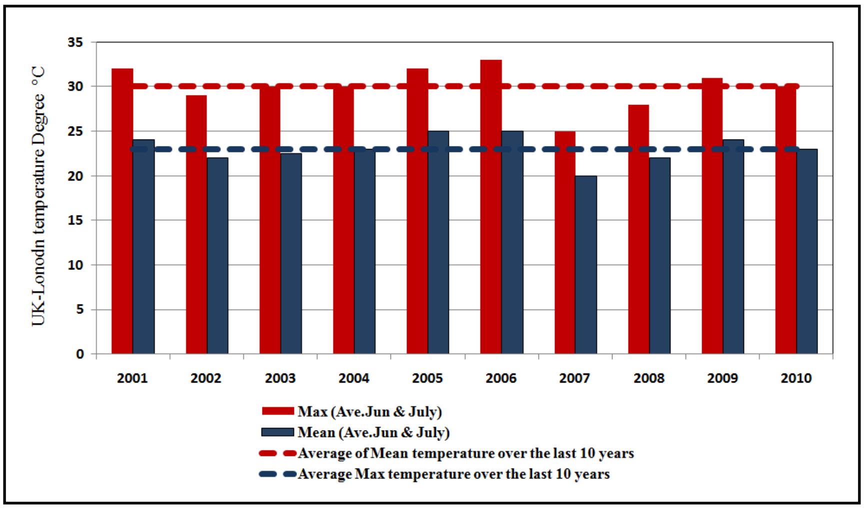

Figure 6: June and July London temperatures during last 10 years

In the following pie-charts (Figure 7), the shares of occurrence of overheating in different schools based on fixed models (derived from Table 3) are summarised.

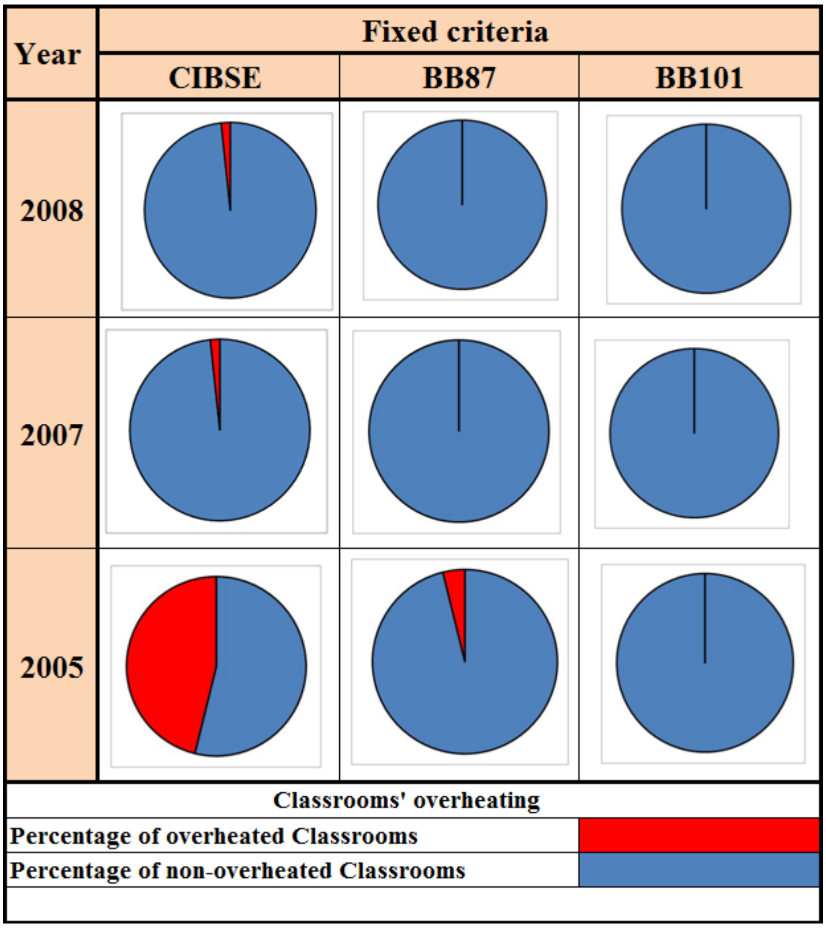

Figure 7: Percentages of overheated and non-overheated classrooms

As a result, the indoor temperature of 139 classrooms were compared with different overheating criterion (based on the fixed model) and concluded that the Building Bulletin criteria (BB101) which is currently used as the design benchmark for schools is the most relaxed criterion. CIBSE is the most stringent one among the fixed models. In fact, BB101 is more insensitive than BB87 and BB87 more than CIBSE.

This could be one of the reasons that the classrooms which are designed/ refurbished based on this criterion could experience overheating. Based on this part of the study, it can be suggested that the BB101 benchmark should be revised. As there are two models for assessing thermal comfort (i.e. fixed and adaptive), the next stage focuses on the assessment the models to identify those which are closer to occupants' feeling.

4.2. Stage two: Study the relation between adaptive and fixed thermal comfort models with schools occupants' perceptions regarding thermal comfort.

In this part, a comparison is carried out between the teachers' perceptions of classroom overheating against the evaluation of overheating based on fixed and adaptive models, in order to establish the accuracy level of the models. In this part, two methods are applied to determine which of the overheating models is closer to the teachers' votes (perception) regarding thermal comfort and consequently more reliable.

<u>4.2.1. First Method: Compare the teachers' votes with overheating dissatisfaction</u>

This section of the research was carried out in the following 3 sections:

a. Section One: Subjective surveys were carried out in 2007 and 2008. In these surveys, the teachers were requested to score their comfort level during summer terms (June & July) on a 7 scale Likert scale for their classroom. One representing comfortable and seven representing uncomfortable.

Thermal comfort	Uncomfortable	1	2	3	4	5	6	7	Comfortable

b. Section Two: The occupied indoor temperature for each classroom is compared with the fixed and adaptive thermal comfort for the duration of the study in 2007 and 2008. The fixed thermal comfort is considered as 25°C. This is a temperature at which occupants start to feel warm according to CIBSE criteria. The occasions that indoor temperatures for each day in each classroom exceed 25ºC are calculated and the results are added together for each classrooms and then for each school.

Furthermore, in this study, the adaptive thermal comfort varies for each day. The adaptive thermal comforts for each day in 2007 and 2008 which is calculated from the following formula are shown in table 4.

$$T_c = 0.33\ T_{rm} + 18.8$$

The occasions that an indoor temperature for each day in each classroom exceeds adaptive thermal comfort are calculated and the result are added for each classroom and then for each school.

2008	Day	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri	Mon
	Date	09/06/2008	10/06/2008	11/06/2008	12/06/2008	13/06/2008	16/06/2008	17/06/2008	18/06/2008	19/06/2008	20/06/2008	23/06/2008	24/06/2008	25/06/2008	26/06/2008	27/06/2008	30/06/2008	01/07/2008	02/07/2008	03/07/2008	04/07/2008	07/07/2008	08/07/2008	09/07/2008	10/07/2008	11/07/2008	14/07/2008	15/07/2008	16/07/2008	17/07/2008	18/07/2008	21/07/2008
	Mean Tout	21.0	19.2	16.4	13.2	13.4	14.4	16.0	15.4	17.0	15.3	16.7	17.4	17.8	16.4	17.5	17.4	20.3	17.5	16.3	16.4	15.1	16.0	15.1	17.2	16.0	18.4	20.6	17.7	16.4	16.9	16.0
	Trm	16.7	17.5	17.9	17.6	16.7	15.6	15.3	15.5	15.5	15.8	16.3	16.3	16.5	16.8	16.7	17.3	17.4	17.9	17.9	17.5	17.1	16.7	16.6	16.3	16.5	15.9	16.4	17.3	17.3	17.2	16.9
	Tc	24.3	24.6	24.7	24.6	24.3	23.9	23.9	23.9	23.9	24.0	24.2	24.2	24.3	24.3	24.3	24.5	24.5	24.7	24.7	24.6	24.4	24.3	24.3	24.2	24.2	24.1	24.2	24.5	24.5	24.5	24.4
2007	Day	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri	Mon	Tue	Wed	Thu	Fri	Mon
	Date	11/06/2007	12/06/2007	13/06/2007	14/06/2007	15/06/2007	18/06/2007	19/06/2007	20/06/2007	21/06/2007	22/06/2007	25/06/2007	26/06/2007	27/06/2007	28/06/2007	29/06/2007	02/07/2007	03/07/2007	04/07/2007	05/07/2007	06/07/2007	09/07/2007	10/07/2007	11/07/2007	12/07/2007	13/07/2007	16/07/2007	17/07/2007	18/07/2007	19/07/2007	20/07/2007	23/07/2007
	Mean Tout	18.4	18.6	18.2	18.1	17.1	16.0	18.6	18.1	17.0	15.7	13.8	13.5	14.1	14.8	17.3	16.0	15.5	15.5	16.1	16.3	14.8	15.3	16.7	18.3	19.0	19.4	17.4	18.1	17.5	16.8	16.0
	Trm	17.5	17.7	17.9	17.9	18.0	17.2	17.0	17.3	17.5	17.4	16.3	15.8	15.4	15.1	15.0	16.0	16.0	15.9	15.8	15.9	16.1	15.9	15.7	15.9	16.4	17.8	18.1	17.9	18.0	17.9	16.9
	Tc	24.6	24.6	24.7	24.7	24.7	24.5	24.4	24.5	24.6	24.5	24.2	24.0	23.9	23.8	23.8	24.1	24.1	24.0	24.0	24.0	24.1	24.0	24.0	24.1	24.2	24.7	24.8	24.7	24.7	24.7	24.4

Table 4: Mean outside temperature, Mean running temperature and thermal comfort for the duration for duration of the 2007 and 2008 studies

c. Section Three: Two regression analyses were carried out between the results of the above:

- Between the teachers' votes and the percentage of occasions that indoor temperatures exceed fixed thermal comfort (i.e. greater than 25°C) for 2007 & 2008.
- Between the teachers' votes and the percentage of occasion that indoor temperatures exceed adaptive thermal comfort (Tc = 0.33 Trm +18.8) for 2007 & 2008.

The results show that the teachers' votes on their satisfaction from indoor temperature (comfortable and uncomfortable) have a correlation (R) of 0.64 where the indoor temperatures exceed adaptive thermal comfort while this correlation is reduced to 0.46 when the indoor temperature exceed fixed thermal comfort in the years of 2007 & 2008.

In other words, a regression analysis between the teachers' votes on the indoor temperature with the occurrence of overheating based on different overheating criteria shows that there is a higher relation between teachers' votes with the adaptive thermal comfort than the fixed thermal comfort.

The following graph (Graph 8) shows the correlation between teachers vote and the percentage of occasions that indoor temperatures exceed adaptive and fixed thermal comfort.

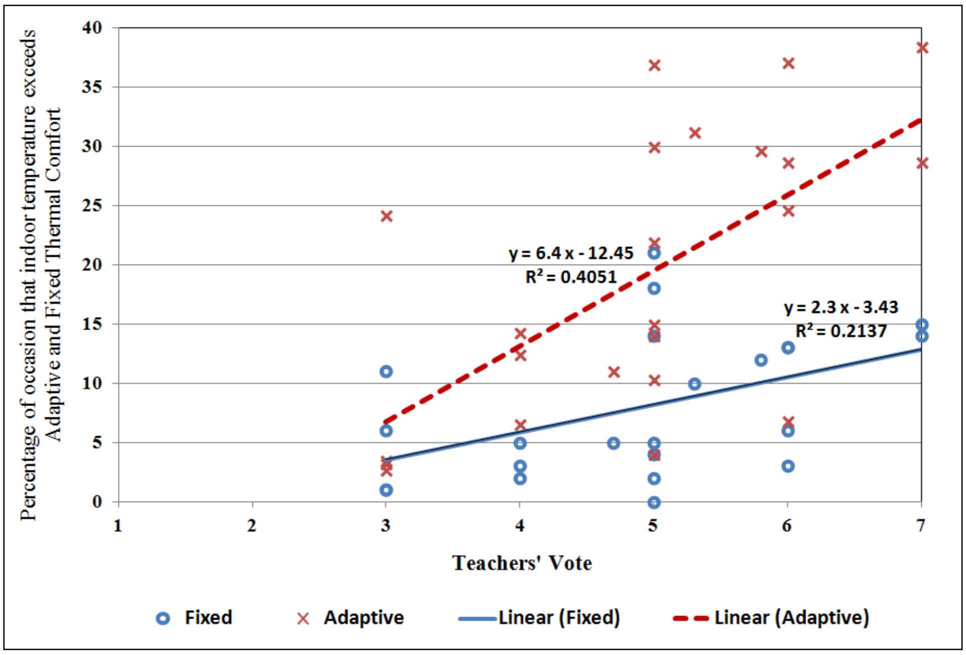

Figure 8: Relation between teachers actual feeling with the occasions that indoor temperature exceeds adaptive and fixed thermal comfort

As it can be seen from Figure 8, there is a higher correlation between the percentage of occasions that exceed adaptive thermal comfort ($R=0.64$, $P<0.05$) than fixed thermal comfort ($R=0.46$, $P<0.5$).

4.2.2. Second Method: Second method: Distribution of indoor temperature

The first method has proven that the adaptive model is a better criterion than the fixed model for assessing overheating in classrooms.

The distribution of indoor temperature is an alternative way to compare the teachers'' votes on overheating with the fixed and adaptive model.

The average distributions of 15 schools' indoor temperatures are shown in the Graph 9 and Graph 10 for the years of 2007 & 2008. As can be seen, only a small portion of the indoor temperatures exceeded 25°C & 28°C.

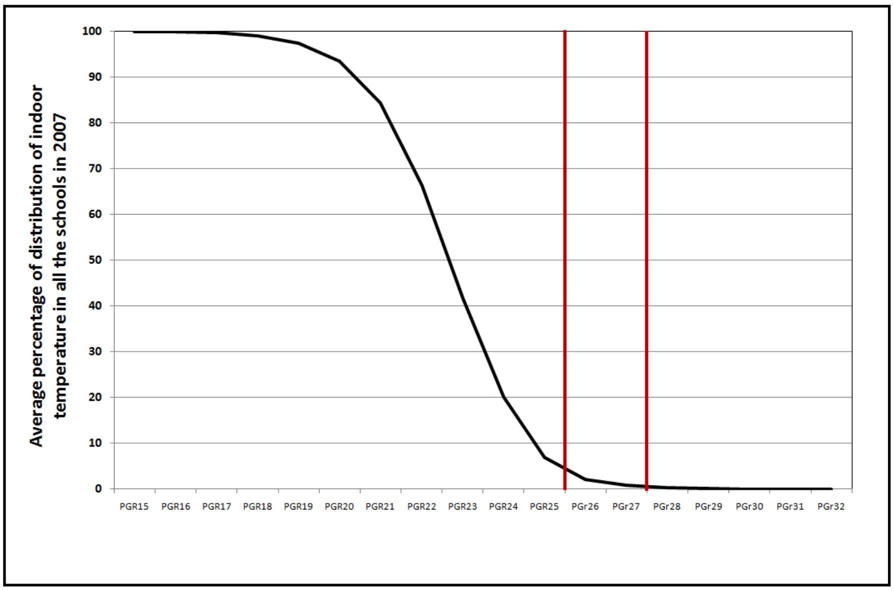

Figure 9: Classrooms' indoor temperature distribution in 2007

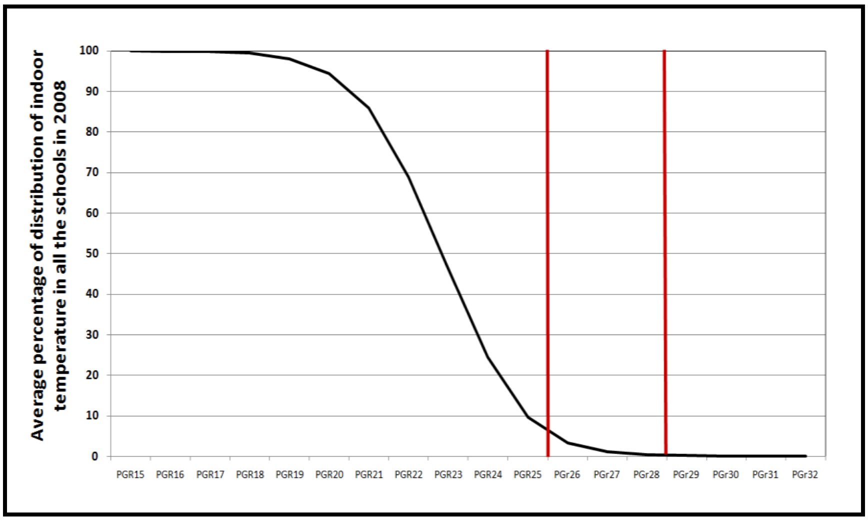

Figure 10: Classrooms' indoor temperature distribution in 2008

As can be seen from Figures 9 and 10, the schools' indoor temperatures rarely exceeded 25°C and hardly exceeded 28°C for the duration of the study. Consequently, the occupants of these schools should not significantly have felt thermally uncomfortable if evaluated on the basis of the fixed model. But the results of the questionnaires on thermal comfort show that the teachers were significantly thermally uncomfortable in June and July of the years 2007 & 2008 (Graph 11 and 12). The teachers' responses which had a tendency towards uncomfortable in 8 out of 9 primary schools is proof of this claim (above scale of 4). This can be seen in the Graph 11 and Graph 12.

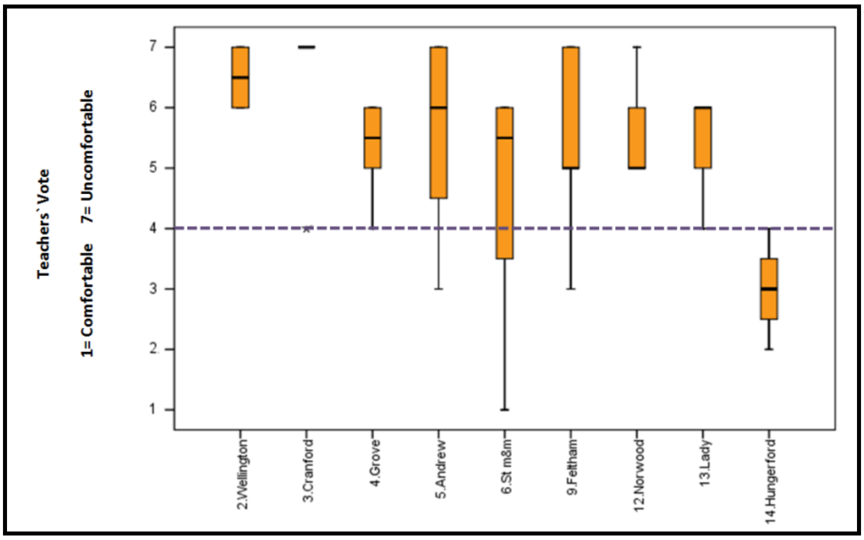

Figure 11: Teachers' comfort level toward thermal comfort in each school in 2007

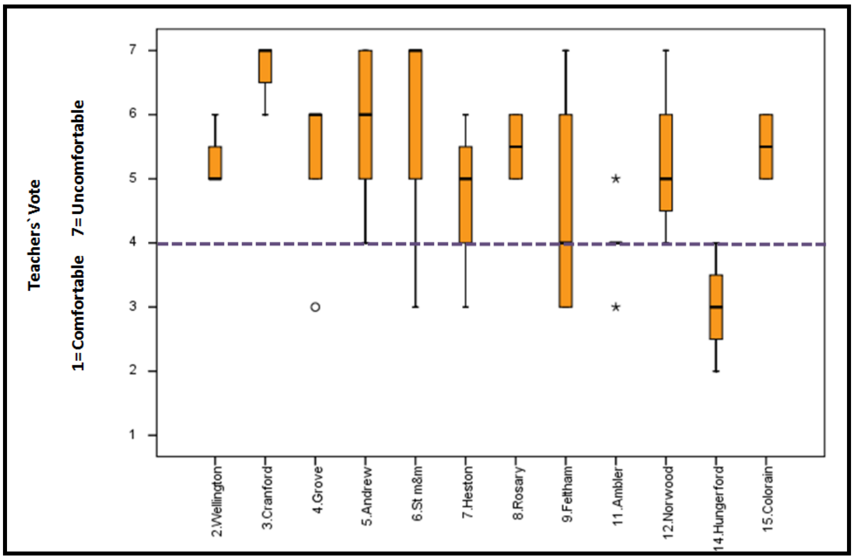

Figure 12: Teachers' comfort level toward thermal comfort in each school in 2008

From the first and second method, it can be concluded that the fixed model does not significantly represent the teachers' voices.

As a result of this part it can be suggested that occupants' feelings about thermal comfort is more related to the adaptive thermal comfort rather than fixed thermal comfort. For this reason it is recommended that thermal comfort benchmarks to be revised based on adaptive model rather than fixed model.

4.3. Stage three: Compare indoor temperature with adaptive model

As it is shown in the first part of the study, the current UK thermal comfort benchmark (BB101) for schools, is the most insensitive one among fixed thermal comfort benchmarks (BB87 and CIBSE). In the second part of this study, it is shown that there is a higher relation between teachers' votes regarding thermal comfort with adaptive thermal comfort rather than fixed thermal comfort. In this part, indoor temperatures are compared with the Nicol criterion which is based on the adaptive model. In his theory, it is possible to calculate the percentage of people who may overheat and the result can be used to categorise classrooms to highly overheated, moderate overheated and low overheated.

Table 5 shows the predicted percentages of occupants who are overheated (thermal dissatisfaction) inside each classroom of various schools based on Nicol formula.

Year	School's Name	Hounslow				Wellington			Cranford			Grove Road							
2008	Classroom's Name	8.1	8.2	8.3	8.4	8.1	8.2	8.3	8.1	8.2	8.3	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8
	Mean	8	4	4	6	3	5	4	7	7	6	7	8	6	7	6	8	5	4
	Max	41	23	14	30	15	16	16	22	25	25	19	25	23	25	19	24	15	13
2007	Classroom's Name	7.1	7.2	7.3	7.4	7.1	7.2	7.3	7.1	7.2	7.3	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8
	Mean	7	3	2	4	2	4	5	6	5	6	6	5	6	5	6	5	6	4
	Max	36	18	14	22	10	12	20	26	15	22	18	18	22	18	18	15	18	18
2005	Classroom's Name	5.1	5.2	5.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Mean	13	12	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Max	78	85	73	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Year	School's Name	Andrew					STMM				Heston			Rosary			Feltham			Pools		
2008	Classroom's Name	8.1	8.2	8.3	8.4	8.5	8.1	8.2	8.3	8.4	8.1	8.2	8.3	8.1	8.2	8.3	8.1	8.2	8.3	8.1	8.2	8.3
	Mean	3	6	6	12	5	6	-	6	7	4	4	11	4	4	3	3	7	3	5	6	7
	Max	9	14	17	35	18	15	-	13	15	16	21	74	15	20	8	10	26	9	16	18	21
2007	Classroom's Name	7.1	7.2	7.3	7.4	7.5	7.1	7.2	7.3	7.4	7.1	7.2	7.3	7.1	7.2	7.3	7.1	7.2	7.3	7.1	7.2	7.3
	Mean	4	4	4	5	5	6	7	6	5	4	3	9	3	3	3	4	6	3	4	5	5
	Max	17	12	20	18	24	16	22	17	17	11	10	64	11	12	29	10	12	8	12	14	15
2005	Classroom's Name	5.1	5.2	5.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.1	5.2	5.3
	Mean	7	9	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	6	7
	Max	46	33	35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	35	31	31

Year	School's Name	Ambler			Norwood			Lady			Hungerford							Colerain			Orchard		St.Gildas				Green church			
2008	Classroom's Name	8.1	8.2	8.3	8.1	8.2	8.3	8.1	8.2	8.3	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.1	8.2	8.3	8.2	-	-	-	-	-	-	-	-	-
	Mean	5	4	3	5	5	12	3	7	5	4	4	3	3	3	2	4	2	2	5	2	-	-	-	-	-	-	-	-	-
	Max	14	14	6	22	25	46	6	26	27	8	16	9	9	12	7	10	14	8	19	19	-	-	-	-	-	-	-	-	-
2007	Classroom's Name	7.1	7.2	7.3	7.1	7.2	7.3	7.1	7.2	7.3	7.1	7.2	7.3	-	-	-	-	7.1	7.2	7.3	7.1	7.2	-	-	-	-	-	-	-	-
	Mean	5	5	4	4	5	9	3	4	4	4	4	3	-	-	-	-	3	2	3	3	5	-	-	-	-	-	-	-	-
	Max	30	18	10	15	17	42	8	10	11	8	15	6	-	-	-	-	12	47	14	15	39	-	-	-	-	-	-	-	-
2005	Classroom's Name	5.1	5.2	5.3	-	-	-	-	-	-	5.1	5.2	5.3	-	-	-	-	5.1	5.2	5.3	-	-	5.1	5.2	5.3	5.4	5.1	5.2	5.3	5.4
	Mean	6	6	10	-	-	-	-	-	-	8	4	5	-	-	-	-	10	5	9	-	-	5	6	6	-	5	4	8	8
	Max	31	24	45	-	-	-	-	-	-	37	18	25	-	-	-	-	58	37	49	-	-	29	35	35	-	18	39	54	48

Color Code	
Highly overheated ≤ 10	(red)
Moderate overheated 6 ≤ & < 10	(orange)
Low overheated <6	(yellow)
Missing data	(grey / white)

Table 5: Study of the percentages of occupants' dissatisfaction from overheating based on Adaptive model in various schools

As can be seen from Table 5, classrooms are categorised into the following groups, based on the percentage of occupants' dissatisfaction from overheating.

- Highly overheated classrooms refer to the classrooms in which more than 10% of occupants feel overheated.
- Moderate overheated classrooms refer to the classrooms in which 6% to 10% of occupants feel overheated.
- Low overheated classrooms refer to the situation in which less than 6% of occupants feel overheated.

The above is based on normal level of expectation in new or renovated buildings with occupants who are not sensitive and fragile (i.e. disabled, sick, very young children and elderly persons).

In a condition that a classroom is occupied by very sensitive and fragile persons with special requirement like disabled, sick children, high level of expectation is required. In this condition, a classroom is highly overheated if only 6% of occupants feel overheated.

In the pie-charts in Figure 13 the percentage of classrooms that were overheated (in different level of highly, moderate and low) in 2005, 2007 and 2008 is summarised.

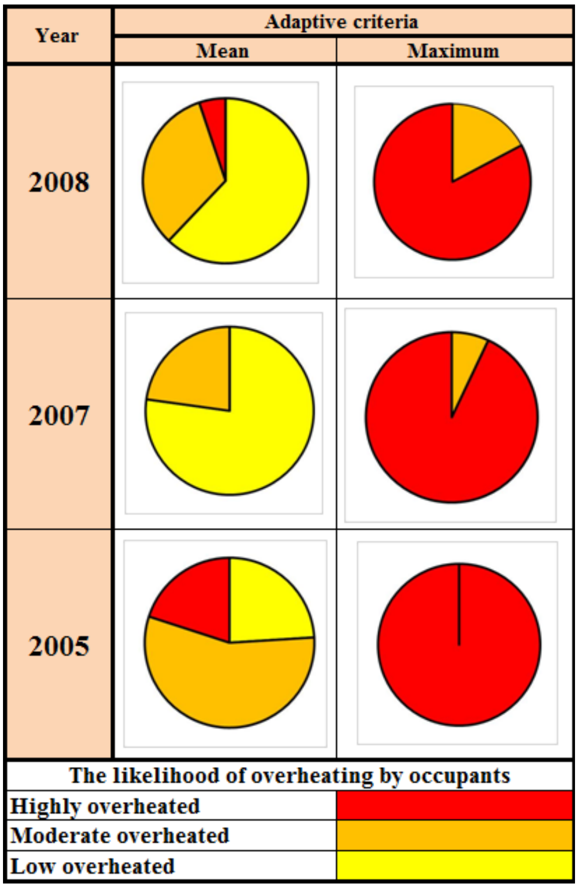

Figure 13: The summary of evaluating classrooms' indoor temperatures based on Adaptive model

As it can be seen in Figure 13 the number of schools (and consequently, their classrooms) which are highly overheated in 2005 is greater than that of 2007 and 2008 (Mean column). In all schools, there is always an occasion when classrooms are highly overheated. These data are based on normal expectations with normal occupant.

5. Conclusion:

As a result of this study, it can be suggested that the two main reasons for poor environmental conditions in UK schools are: firstly the conflict between comfort factors (thermal, lighting, acoustic comfort and air quality) as they are interrelated and secondly, the use of the insensitive thermal, air quality, acoustic and lighting benchmarks for their design.

The Nicol thermal criterion is not only designed based on the adaptive model which has a better relation with occupants' feeling, but also provides detailed information regarding overheating by predicting the percentage of people that may feel overheated and considering the type of occupants inside classroom, while overheating criteria based on fixed model only determine whether the classrooms are overheated or not. As a result, there is a gap between predicting thermal comfort (based on the fixed model) and actual occupants feeling inside a classroom.

Based on this study, it can be suggested that one of the reasons for overheating in UK school buildings is that they are designed based on the least sensitive thermal design criteria (Building Bulletin 101). As a result, it is suggested that the current building design thermal benchmark (i.e.BB101) for the UK primary schools be revised considering the Nicol formula.

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