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Rethinking of Design Excellence via Building Performance

With Particular Reference to the RIBA Award-winning Schools in the UK

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ABSTRACT

Too often, buildings do not correspond to the original design aspirations of designers. This PhD project aims to investigate whether or not buildings branded as exhibiting 'design excellence' perform well in practice, focusing on the quality of the indoor environment and the satisfaction of occupants. It also intends to explore how to ensure that buildings with design quality achieve good performance in use.

Buildings which won reputable design awards are assumed as exhibiting design excellence acknowledged by the architectural profession. With the need for sustainable schools with design quality, the Post-occupancy Evaluation (POE) studies of five RIBA Award-winning schools were conducted in this research, using the case study approach for two years, in order to investigate actual performance of the schools branded as exhibiting design excellence. The POE studies which measured building performance, i.e. environmental performance and energy performance, and architectural performance, i.e. user feedback, handover issues, management and maintenance, were carried out in each of the case studies. The evaluation results were then compared with the latest environmental standards and the corresponding benchmarks.

The case studies show that not all the schools studied achieved good performance in practice. Common issues emerged in four of the five schools, related to daylighting, overheating issues, the use of low carbon technologies, gaps between predicted and actual energy performance and occupant experience – use of controls. It indicates that receiving architectural excellence awards cannot assure good performance in use, and hence the 'performance gap' between the original design intention of the designers and actual building performance. The performance gap was found due largely to the inappropriate design decisions related to environmental design issues and improper operation and maintenance in use, besides the issues related to construction process which was not studied in this research. The design-related factors – design process and aftercare service – were inferred to have a great impact on building performance.

This research project results in three contributions to existing knowledge and practice. The first contribution is to provide guidance for the evaluation of building performance of non-domestic buildings, especially schools. The guidance is composed of three key performance indicators (KPIs) that can be further divided into seven performance indexes, allowing the evaluation undertaken in a holistic manner rather than simply relying on an individual

asset. The second contribution is to summarise challenges and constraints in conducting POE studies of schools. Specific recommendations regarding how to collect meaningful data for POE studies of schools were provided, which can be used as a reference for others. The third contribution is the analysis of the impact of design process and aftercare service on building performance and the corresponding suggestions of judging building performance in the RIBA Awards. As it is difficult to judge actual performance of a project in design award schemes due to the 'time' effect of awards, the awards submission is suggested to stress on documentation related to these elements in order to assist the jury to judge building performance in a sensible manner.

This research highlights the importance of understanding and assessing building performance in determining design excellence. Building Performance Evaluation (BPE) should be made mandatory for all entries for the RIBA Awards and other architectural excellence awards. Alternatively, architectural design awards could be judged on actual performance of the buildings which received the awards after a few years of occupation through a valid POE study. With the technical nature of POE studies, it suggests POE studies for award-winning buildings to be done by a third party.

LIST OF PUBLICATIONS

Publication 1

Chen, Y. and Ford, B. *How Do Occupants Perceive the Building Performance of Award-winning Schools in the UK*. In: Lang, W., eds. *Sustainable Architecture for a Renewable Future*, 29th International Conference on Passive and Low Energy Architecture, Munich, Germany, September 2013. Munich: Fraunhofer IRB Verlag, 2013

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ACRONYMS / ABBREVIATIONS

BPE	Building performance evaluation
BRE	Building Research Establishment
BREEAM	Building Research Establishment Environmental Assessment Methodology
BUS	Building Use Studies
BSRIA	Building Services Research and Information Association
CABE	Commission for Architecture and the Built Environment
CIBSE	Chartered Institution of Building Services Engineers
CIC	Construction Industry Council
DA	Daylight autonomy
DCSF	Department for Children, Schools and Families
DEC	Display Energy Certificate
DF	Daylight factor
DfE	Department for Education
EBD	Evidence-based design
EFA	Education Funding Agency
EPC	Energy Performance Certificate
FCBs	Feilden Clegg Bradley Studios
HCC	Hampshire County Council
IEQ	Indoor environment quality
KPIs	Key performance indicators
PfS	Partnerships for Schools
POE	Post-occupancy evaluation
PROBE	Post-occupancy Review Of Buildings and their Engineering
P&P	Penoyre & Prasad architects
RIBA	Royal Institute of British Architects
RICS	Royal Institution of Chartered Surveyors
SWA	Sarah Wigglesworth Architects
UBT	Usable Building Trust
UDI	Useful Daylight Index
UR	Uniformity ratio
ZCTF	Zero Carbon Task Force

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Chapter 1 Introduction

As an architectural designer, I have been pursuing answers to two questions since graduating from university – '*what is design excellence in architecture?*' and '*how to deliver architecture with good performance in practice?*' This doctoral thesis explores answers to these questions, and this is an UK-based research.

1.1 Research context

1.1.1 Background

In the built environment, architecture plays a vital role in providing space for individuals to live, work and feel, and also makes us recognise what is special about our society and communities. It is essential to design buildings with fabulous appearance, but good architecture is about much more than how architecture looks.

> *"*Good design is about to improve the quality of life for everyone*"* (CABE[1], 2006).

When it comes to discussing 'what is good architecture', it is difficult to provide a fixed definition due to the complex nature of architecture, whereas it is possible to judge whether a building is well designed or not based on what qualities it embodies and how it performs in practice. The identification of good architecture is always a combination of multiple criteria that equate to

[1] Commission for Architecture and the Built Environment (CABE) was the government's advisor on architecture, urban design and public space from 1999 to 2011.

values individuals may not agree upon (Langston, 2014). The Roman architect Marcus Vitruvius Pollio (circa 15 B.C.) claims that three principles should be achieved: "*firmness, commodity* and *delight*" (Wotton, 1685). These three fundamentals have been later transferred into: robustness, or durability; usefulness, or efficiency; and beauty, or the ability to delight people, indicating the essence of a good building that it should be stable enough to protect itself and to protect its occupants keeping them warm and dry in winter and cool in summer; should have efficient spatial arrangement to fulfil the demand of different activities; and should achieve 'architectural beauty' to delight its occupants and others (Pollio and Morgan, 1960; Pollio and Smith, 2003). These principles emphasise the relationship between architecture, human beings and the environment, and they have been still used as chief criteria to judge the design quality of architecture nowadays.

With architecture has become one of the chief sources of environmental pollution – accounting for a considerable proportion of net energy consumption in the countries of the industrialised world[2] and approximately 40% of the developed countries' greenhouse gas emissions – the environmental function of architecture has been paid more attention to since the 'energy crisis' of the 1970s. The governmental and institutional pressures are influencing architects to produce progressive improvements in the *performance* of buildings for the realisation of low-energy, 'environmentally responsible' buildings in response to the climatic change and 'peak oil' (Hawkes et al., 2002). Many architects and scholars (Wotton, 1685; Olgyay, 1963; Banham, 1969; Sala et al., 1999; Hawkes et al., 2002; Williamson et al., 2003) have also underlined the great impact of architecture's performance on the inhabitant's health and productivity,

[2] Buildings account for 38% of the U.S.'s carbon emissions (DOE, 2008) and 37% of the UK's greenhouse gas emissions (DTI, 2005).

as well as the environment.

> *"The nature of the problem of building energy demand has been recognised since the so-called 'energy crisis' of the 1970s. The connection between buildings and environmental pollution, however, has been acknowledged only in recent years"*(Hawkes et al., 2002, p. 2).

Gordon (1972) argues that buildings should be designed for "*long life, loose fit and low energy*", considered as '3L Principle' for good architecture (Langston, 2014). As per the 3L Principle, the idea of buildings for permanence, yet containing flexibility to adapt for future change and minimising carbon footprint throughout its physical life, is deemed as the ultimate holistic aim for the architecture profession (Murray, 2011). In addition, to satisfy the inhabitants by producing places that work well and last is deemed as the must-achieve feature of good design (Gann et al., 2003). As such, a well-designed building should be affordable, positively following the change of climate, natural context and occupant's requirements (CABE, 2006).

> *"Good architecture lies in the care with which buildings are designed to provide long-term benefits to the society they serve, and transcend the utilitarian and the fashionable in favour of performance and legacy"* (Langston, 2014, p. 163).

1.1.2 Research hypothesis

Definitions of quality in design are elusive, as design quality often consists of both objective and subjective components (Gann et al., 2003). However, it is possible to distinguish 'good' design from 'poor' design based on the qualities

it encompasses (CABE, 2006).

When it comes to judging design excellence in architecture, architectural awards, particularly prestigious awards with broad social impact and high reputation in the architectural profession, have acted as professional 'benchmarks' to set up high standards for quality buildings and to promote design excellence in architecture. At the present time, a number of buildings worldwide receive architectural design awards each year as a result of the attribution of their design quality to the evolution of architecture. In general, the jury judge design quality of buildings on the basis of their achievement in accordance with awards criteria, which usually embrace the three qualities proposed by Vitruvius, i.e. firmness, delight, and commodity (Wotton, 1685). It is reasonable to assume that award-winning buildings are acknowledged by the profession, to a large extent, as the achievement of 'design excellence' in architecture.

In recent years, with 'sustainability' has been deemed as an important element of good architecture according to the responsivity of architecture to the climate change crisis, there have been increasing architectural awards established to judge building design in a sustainable manner. In the UK, several awards are explicitly focused on performance of buildings, including CIBSE (Chartered Institute of Building Services Engineers) Building Performance Awards, BREEAM (Building Research Establishment Environmental Assessment Methodology) Awards and RIBA (Royal Institute of British Architects) Sustainability Awards. Sustainability examined in these awards is concerned not only environmental performance but also site issues, use of materials, construction and handover, energy and carbon performance in use (Gething and Bordass, 2006). Nevertheless, for many architectural *design* awards nowadays,

building performance has been rarely involved as a key criterion in the awards judgement. This could be due to the emphasis on different aspects of 'sustainability' differed widely across the projects, hence increasing the judging difficulties (ibid.). On the other hand, it is possible to assume that building performance may be lack of considerations when it comes to design excellence.

Since 1966, the RIBA Awards – a prestigiously architectural design awards programme in the UK – has been established to promote excellent buildings and their contributions to communities and the environment, consisting of Regional and National Awards, Stirling Prize and some special Awards. Now working with the Government, it seeks to improve the design quality of new domestic buildings, public buildings and new communities. Every scheme is judged by the jury (RIBA members and lay assessors) based on the criteria of RIBA Awards, looking into a scheme's achievement in terms of balancing the complexities that any building project will have faced with aesthetic, sustainability and perhaps conservation considerations, as well as the local context (RIBA, 2014).

> *"It requires an examination of the client's brief and how intelligently and creatively that has been fulfilled, whilst taking into account the constraints of budget and planning. It means taking a collective view and having a clear vision on what constitutes architectural excellence"* (RIBA, 2014).

The specific criteria of the Awards are displayed in the RIBA's documentation attached in Appendix 6, looking into a scheme from five aspects – architectural performance, sustainable performance, client and user satisfaction, social impact and economic performance. Within each aspect, individual topics related to 'design excellence' are clearly listed in Figure 1.1-1. According to

Figure 1.1-1, it can be noticed that '*sustainability*' and '*client and occupant delight'*, which relate to building performance, have been considered as chief criteria of the Awards, besides aesthetics, innovation, functionality and others. Over the last decade, an increasing number of buildings have received RIBA Awards which explicitly attempt to address environmental design issues and reduce fossil fuel energy use. Accordingly, it is rational to presume that *the RIBA Award-winning projects represent high-level design standards and should have achieved both good building performance in practice and occupant satisfaction.* This is the main premise of this research.

> *"The project should demonstrate design excellence, that it should be fit for purpose and that it should be sustainable"* (RIBA, 2014).

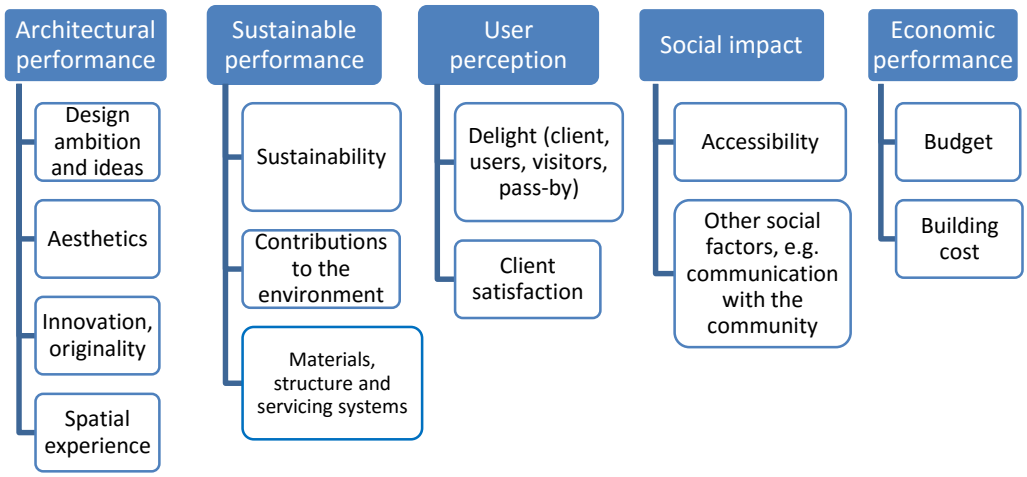


Figure 1.1-1: Chief criteria of the RIBA Awards, judging design of buildings from five aspects (source: RIBA).

1.2 Research question

1.2.1 Limitations of RIBA Awards in judging building performance

When it comes to assessing building performance, it usually targets to address two questions – 'how does a building perform in practice, with particular reference to energy performance in use?' and 'how do occupants perceive a buildings in use? To answer these questions, energy performance in use, CO_2 emissions, and management and maintenance have been frequently used as key performance indicators (KPIs) for the assessment of building performance. In addition to these indicators, occupant satisfaction regarding the indoor environment and the use of controls is useful to reflect building performance, albeit sometimes subjective (Baird and Lechat, 2009; Lee and Guerin, 2009; Chen and Ford, 2013).

Based on the research hypothesis raised in Section 1.1.2 – the RIBA Award-winning buildings should reach both design quality and good performance – it is reasonable to infer that the factors related to building performance, such as energy performance in use, CO_2 emissions and user satisfaction mentioned previously, should have been judged thoroughly in the Awards. However, it is surprisingly to find that merely one parameter - 'energy performance in use' presented by annual energy figures and energy statistics provided by the entrants – has been considered when assessing the performance-related topic (i.e. sustainability) in the Awards, in accordance with the documentation of RIBA Awards attached in Appendix 6. For the Awards entry which has not been occupied for a year, projected energy figures are required for the assessment.

There is significant evidence to suggest that buildings do not perform as intended, hence the "Performance Gap" (Bordass et al., 2004; Menezes et al.,

2012; Gupta and Dantsiou, 2013). According to *Building Evaluation Performance Non-domestic Final Report* which displays the latest findings of Innovate UK's Building Performance Evaluation programme (BPE)[1] published in 2016, on average, buildings were using 3.6 times as much energy as they were designed to use, highlighting the credibility gap between the 'as designed' energy performance and the performance in use (Palmer et al., 2016). With all entries for RIBA Awards are newly-designed buildings, i.e. usually occupied less than two years (RIBA, 2014), annual energy figures and energy statistics provided by the entrants could be somewhat undependable and sometimes projected figures, consequently influencing the reliability of the judgement to a certain degree.

To assess an architectural project's performance, post-occupancy evaluations (POE) and building performance evaluations (BPE) are the methodologies often used. With these methodologies are comparatively technical and some of the products are also commercial that they need paying for, they have been rarely conducted in the judging of architectural awards. According to Gething and Bordass (2006), projects which reached the shortlist for RIBA Regional and National Awards had not been subject to any consistent sustainability assessment (Gething and Bordass, 2006, p. 417). Gann et al. (2003) also note that award systems based on peer review within the professions rarely provide an opportunity to engage users and create a dialogue between actors on a specific project about the goals and design of that project.

For the approach to assessing building performance in RIBA Awards (i.e.

[1] Innovate UK's Building Performance Evaluation programme (BPE) was a 4 year study into how real-world buildings perform. Building performance of over 100 projects, particularly energy performance in use, was assessed in the programme, covering from schools to apartments, supermarkets to offices, health centres to houses.

Regional and National Awards), it consists of two steps – the judges initially compare the energy performance provided by the entrants with the relevant benchmarks (e.g. Part L and CIBSE TM22), and site visits are then undertaken for the projects that reached the benchmarks. For the site visits, it is noteworthy that the jury usually visit a project with the architect and the client, whereas end users of the project may not be involved or interviewed, hence possibly limited information regarding user satisfaction collected.

The project which reached the shortlist of RIBA Regional and National Awards will be entered the judging for RIBA Sustainability Awards which is explicitly focused on sustainable performance of buildings. In this Awards programme, the project would be assessed according to a Checklist adapted on the basis of the sustainability 'Matrix' developed by Feilden Clegg Bradley Architects (FCBs) with others. In the Checklist, nine sections of topics related to the order of decision-making in an architectural project are involved: starting with strategic aspects of the site, then how the land was used, what the building was like, of what it was made, how it was likely to work, its likely impact on its occupants and the environment, how it was actually built, and how it was performing in use (see Figure 1.2-1). Each section was further broken down into items for which specific targets were developed against six main levels of aspiration: Below stand, Standard, Good practice, Best practice, Innovative and Pioneering. Borderlines were inserted between two neighboured levels, allowing more precise assessment (see Figure 1.2-2). Both the design team and the jury are asked to rate the project's performance level based on the Checklist for a comparison, and the judges will finally make a decision using a summary spreadsheet that set the scores (-1 for Substandard, 0 for Standard, through to 4 for Pioneering) for each topic for each shortlisted building side by side.

CONTEXT

1	**Choice of site**
1.1	Refurbishment, brownfield, greenfield
1.2	Proximity to public facilities and services
1.3	Transport policy, proximity to public transport
1.4	Proximity to housing and/or employment
1.5	Robustness against impacts of change (e.g. flooding)

DESIGN CHOICES

2	**Use of site**
2.1	Ecological quality of site
2.2	Use of land
2.3	Biodiversity
2.4	Community integration
2.5	Infrastructure enhancement
3	**Building form**
3.1	Location of building on site
3.2	Re-use of existing buildings
3.3	External environmental impact (visual, noise, microclimate)
3.4	Adaptability potential
4	**Use of materials**
4.1	Selection for low environmental impact
4.2	Potential for re-use and recycling
4.3	Good thermal performance
4.4	Low embodied energy and pollution
4.5	Low toxicity

DESIGN AND CONSTRUCTION PROCESS

8	**Construction & handover**
8.1	Briefing and design reviews
8.2	Considerate constructor
8.3	Environmental impact of operations on site
8.4	Environmental impact of transport to site
8.5	Sourcing of materials, components and labour
8.6	Waste minimisation during construction
8.7	Fitout
8.8	Commissioning, handover, training, soft landings
8.9	Incorporating post-occupancy evaluation and feedback

OUTCOMES (design predictions, replace by actual when in use)

5	**Functionality**
5.1	Controls, controllability and manageability
5.2	Provision for maintenance
5.3	Provision for waste management
5.4	Resistance to climate change impacts
5.5	Durability
6	**Indoor environment**
6.1	Acoustic
6.2	Air quality
6.3	Lighting
6.4	Thermal
6.5	Spatial
7	**Energy, CO_2 & utilities**
7.1	Energy efficiency
7.2	On-site CHP and renewable energy
7.3	**Emissions to atmosphere (principally CO_2)**
7.4	Water
7.5	Liquid wastes: avoidance, drainage systems, water treatment
7.6	Solid wastes, waste management

ACHIEVED PERFORMANCE (if information is available)

9	**Performance in use**
9.1	Impact on local environment community, townscape, transport etc.)
9.2	Fitness for purpose
9.3	Appropriateness of space
9.4	Appropriateness of fitout
9.5	Usability and manageabiilty *(update Section 5)*
9.6	Indoor environmental quality *(update Section 6)*
9.7	Occupant satisfaction
9.8	Use of energy and utilities *(update Section 7)*
9.9	Quality of building and facilities management

Figure 1.2-1: The nine main groupings of the sustainability Matrix and the individual topics within them (source: Gething and Bordass, 2006).

How would you rate your building and site? *Please put a tick or a comment in one box in each row. If there is independent verification, please put a tick in the boxes to the right, or enter the source (e.g. BREEAM). Please add comments or append material if you want to.*	Below standard	Borderline	Standard	Borderline	Good practice	Borderline	Best practice	Borderline	Innovative	Borderline	Pioneering
Name *Building name goes here*	*e.g. Poor location*		*e.g. Building Regs 2002*		*e.g. BREEAM very good*		*e.g. BREEAM excellent*		*Rare*		*Exceptional*

CONTEXT

		please put a tick (or a 1 if using Excel) in only one box in each row below
1	**Choice of site**	
1.1	Refurbishment, brownfield, greenfield	
1.2	Proximity to public facilities and services	
1.3	Transport policy, proximity to public transport	

Figure 1.2-2: Extract from the checklist showing the 11-point scale (source: Gething and Bordass, 2006)

The approach described above is considered as a "*quick, simple, robust and fair approach*" to help with judging the RIBA Sustainability Awards (Gething and Bordass, 2006, p. 416). Comparing this approach with the one used to assessing building performance in RIBA Awards (i.e. Regional and National Awards), it can be found that several essential factors which can effectively

reveal actual building performance have been disregarded in the judging of RIBA Awards, such as indoor environment quality and occupant satisfaction. On the other hand, the energy performance evidence provided by the entrants could be lack of accuracy due to the relatively short period of occupancy.

The above examination regarding the judging and criteria of RIBA Awards exposes the limited considerations of building performance and user satisfaction in the Awards. This could be due to the difficulties of technical issues in the assessment of building performance, as well as the limited financial budget. Nevertheless, it is possible to infer that building performance may be considered less important to 'design excellence' in comparison with design quality in the judging of the Awards. The limited focus on building performance could result in an unwanted situation that the RIBA Award-winning projects do not perform as well as expected in practice. Accordingly, the primary research question of this thesis is raised – *do the buildings branded as exhibiting 'design excellence' by the RIBA Awards have equivalently good building performance in practice*? To answer this research question, the investigation of performance in use of several RIBA Award-winning projects was conducted in this research.

1.3 Research scope and justification

At the outset of this work, the objective was to investigate whether the buildings which represent 'design excellence' (i.e. RIBA Award-winning buildings) achieve equivalently good building performance in practice. This encompassed undefined 'boundaries', which were initially investigated through literature review.

1.3.1 Research scope

- The need for quality schools with sustainable performance

Non-domestic buildings (i.e. commercial and public) account for about one-sixth of the UK's entire CO_2 emissions and one-third of the building-related ones. Their proportion of energy (particularly electricity) consumption has also been growing (Bordass et al., 2004). Among non-domestic buildings, educational buildings in England act as the third largest contribution to the service sector's energy consumption (Department of Trade and Industry, 2002), emitting approximately 9.4 million tonnes of CO_2 equivalent each year (DCSF, 2010). With the Government's ambitious target of the reduction of four-fifth of carbon emissions by 2050, the demand of sustainable schools with energy efficiency and low carbon emissions has been increasing.

Besides the urgent need of sustainable schools in response to climate change crisis, quality of the school's indoor environment in the UK is required to be improved. In 2006, the original CABE initiated a school review programme, assessing the quality of over 100 secondary schools completed during the previous ten years. In accordance with the review findings, over half of the schools audited by CABE had been assessed as '*mediocre*' or '*not yet good enough',* and environmental issues including lack of natural light and fresh air, overheating issues in summer and poor acoustics occurred commonly in the schools reviewed, indicating that some design mistakes found in previous school design were still experienced by designers nowadays (CABE, 2008).

> *It is clear that there are not enough school being built or being designed that are exemplary, inspiring, innovative, or flexibly designed to allow for a diversity of approaches to education in the future* (CABE, 2011).

Many previous studies have proved that for school buildings, human behaviours, especially children's, have been proved to be easily influenced by surrounding environment (Cotton, 1996), and evidence shows that better-designed schools lead to higher motivation and educational attainment (CABE, 2007). In recent decades, daylighting which is the practice of using natural light to provide illumination in indoor environments has been advocated as a way to reduce lighting energy use in schools, as well as to benefit user well-being and productivity (Heschong et al., 2002; Wu and Ng, 2003; Mardaljevic et al., 2009). The character of daylight changing throughout the teaching day is considered hard to replicate by electrical light. According to BB 90, it requires that natural light during daylit hours should be the primary source in schools supplemented by electrical light (DfEE, 1999).

A study in Sweden shows that observed behaviour and circadian hormone levels of elementary students in classrooms with daylight retain closer to expected norms than those in classrooms with only fluorescent sources, and thus windowless classrooms are suggested to be avoided (Küller and Lindsten, 1992). Another study carried out by Heschong Mahone Group in the U.S. compared test scores performance for 8,000 to 9,000 students from classrooms with different window designs in three isolated districts, particularly looking at their math and reading scores. The study showed that students in classrooms with the most window area or daylighting were found to have 7% to 18% higher scores on the standardised tests than those with the least window area or daylighting (Heschong, 2002). In addition, Heschong (2002) maintains that the presence of operable windows in classrooms is also seen to have a positive effect on student progress, associated with 7% to 8% faster learning (ibid.). She claims a number of potential mechanisms (alone or combined) that may have been responsible for the positive association between daylight and improved

performance of students – “improved visibility due to higher illumination levels; improved visibility due to better light quality, mental stimulation and improved mood, behaviour or well-being” (Heschong et al., 2002, p. 110).

On the other hand, it seems to be generally believed that ‘good’ daylighting design will lead to reductions in electric lighting consumption, and also overall energy consumption. Nevertheless, Mardaljevic (2009) states that daylighting may lead to a net increase in energy consumption if the additional cooling load due to daylight (i.e. including the solar component) exceeds the energy saved due to reduced electric lighting, or if the net heat gains and losses through windows or glazing do not compensate for the lighting energy saved. A full consideration of the potential for daylighting to save energy should account for the thermal effects of daylight (Mardaljevic et al., 2009). In addition to quality daylight, sufficient ventilation, good air quality and limited noise level in classrooms benefit not only children’s learning ability, teacher and staff’s productivity but also energy efficiency of schools (Daisey et al., 2003; Becker et al., 2007). Nevertheless, Edwards (2006) expresses that attention to daylight levels in schools is more important than the current focus upon ‘comfort’ (Edwards, 2006).

According to a study particularly focused on the impact of ‘green’ schools in Hampshire and Essex on the inhabitants, it shows that school buildings designed on green principles offer benefits for the pupil and teacher alike – the quality of the classroom environment resulting from green design approaches appears to “reduce stress in teachers, leading to lower rates of absenteeism or staff turnover, and this in turn leads to improved productivity” (Edwards, 2006, p.29). In addition, Edwards (2006) suggests a relationship existing between design, energy conservation and educational performance, corresponding to the

National Curriculum Council's (NCC) assertion that the "spirit and ethos of the school contributes significantly towards the development of a caring attitude towards the environment" (NCC, 1990).

As above, it is immediately clear that to provide quality schools with sustainable performance meets the needs of education transformation and the Government's sustainable target. Meanwhile, the increasing demand of sustainable schools in the UK requires more attention of designers. As a result, schools were chosen as the research vehicle in this thesis, and actual building performance of the RIBA Award-winning schools became the primary focus of this research. Based on the scope of this research, it investigated the school buildings in the UK which won RIBA Awards, but it is anticipated that the findings will be more wildly applicable.

1.3.2 Research justification

As mentioned previously, the judging factors related to design quality, such as aesthetics and spatial experience, is relatively subjective. There is no fixed standard to assess design quality due to the variation of each architectural design. Within the research context, architectural merits of each of the RIBA Award winners have been acknowledged by the professional judges based on the criteria, whereas building performance has not been judged thoroughly. Thus, the investigation undertaken in this research was not focused on design quality of the RIBA Award-winning projects but building performance.

1.4 Aims and objectives

As per the above research justification, the primary aim of this thesis is to

investigate building performance of the RIBA Award-winning schools and to understand the influence of design factors on building performance hence design excellence. In addition, it intends to provide valuable suggestions regarding assessing building performance in architectural design awards, i.e. RIBA Awards in the case of this research, in order to promote quality buildings which actually perform well.

The specific objectives of this research project are detailed as follows:

Objective 1:

Develop an approach for conducting POE studies of high performing schools (or buildings), i.e. RIBA Award-winning schools in this research, in order to have had a lot of care and support in its production.

Objective 2:

Assess actual building performance of the RIBA Award-winning schools via the approach developed according to Objective 1, in order to find out if there is the 'Performance Gap' between the design aspirations of designers and building performance in use.

Objective 3:

Investigate the essential (design) factors impacting on building performance and how these factors can be managed to improve building performance.

Objective 4:

Rethink of the judging of 'design excellence' in architectural design awards and provide suggestions regarding assessing 'building performance' in architectural awards.

1.5 Thesis structure

This thesis is divided into three parts. Part I includes the introduction, literature review and research methodology. Part II contains a pilot case study and the summary of main findings of the five case studies, and Part III presents the inferences drawn from the case studies and the final conclusion. The thesis is organised into eight chapters. An overview of each chapter is provided below.

Part I:

Chapter One – Introduction

Chapter One presents the research context of this thesis, pointing out that good building performance is the important manifestation of 'design excellence'. Research question and research scope are stated – this thesis investigates whether or not the RIBA Award-winning schools achieve good building performance in practice, intending to explore factors impacting on building performance and hence influencing design excellence.

Chapter Two – Literature review

Chapter Two summarises the findings of a literature review acknowledging previous and parallel research efforts – POE or BPE studies of school buildings already undertaken and their main findings.

Chapter Three – Research methodology

Chapter Three presents the research methodology adopted and the specific methods used in the case studies. It consists of a critical review of POE or BPE methods and the analyses of appropriate POE or BPE approaches for schools. The selection of the case study projects is then introduced.

Part II: Case studies

Chapters Four, Five and Six

Part II describes the case studies undertaken by the researcher to meet the primary aim of this research, particularly addressing Objective 2. It is divided into three chapters – Chapter Four to Chapter Six. Chapter Four describes a detailed case study of a selected RIBA Award-winning school as a pilot case study. The following aspects are included in this chapter – school introduction; design process; chief design strategies employed; the school's environmental performance in terms of daylighting, ventilation and thermal aspect and the school's energy performance in terms of energy efficiency and carbon emissions; POE results – occupant feedback regarding how the school works in practice, and a summary of the actual performance of the school studied. For Chapter Five and Six, the evaluation result of building performance and architectural performance of the schools studied are analysed.

Part III:

Chapter Seven – Common issues across the case studies and the influence of design factors

Chapter Seen firstly summarises building performance of the case study schools, indicating the issue of discrepancies between the design intention of the designers and actual building performance of the schools studied. It then summarises the common issues emerged in the schools studied, analyses the contributing factors to the performance gap and summarises the factors impacting on building performance – design process and aftercare service. Several suggestions for architects to improve building performance are provided at the end of this chapter, particularly meeting Objective 3.

Chapter Eight – Conclusion

The final chapter summarises the main findings of this research, and answers the research question. Suggestions regarding the judgement of building performance in RIBA Awards are provided, underlying the role of building performance when rewarding design excellence. In addition, a discussion of the challenges and constraints of conducting POE studies, particularly in schools, is provided, which can be used as reference for others. The limitations and contribution of this research is shown in this chapter, as well as the anticipation of future work.

Chapter 2 Literature review

This chapter provides an overview of post-occupancy evaluation (POE) in terms of definition, benefits and barriers, and the development to building performance evaluation (BPE). It identifies the importance of conducting POE/BPE studies to assess building performance, benefiting the design industry. The approaches and methods of POE/BPE are reviewed in Chapter 3 Research methodology.

The POE/ BPE studies of schools already undertaken in the UK and the corresponding findings are also reviewed in this chapter, including the original CABE's school review programme, Partnerships for Schools (PfS)'s POE studies of schools, BSRIA's carbon footprinting studies for primary schools, the Soft Landings for Schools project and Innovate UK's BPE programme. The review of the above POE studies of schools indicates that several issues and design mistakes revealed in the past school design have been still found in school design nowadays, emphasising the urgent need of well-designed schools and underling the benefits of conducting POE studies of school buildings.

2.1 An overview of POE

2.1.1 Definition of POE

POE has now been widely used for the assessment of building performance; nevertheless, it is interesting to find out that the POE concept is multiple. POE has been defined by Zimring and Reizenstein (1980) as "examinations of the effectiveness for human users of occupied design environments" (Craig M.

Zimring, 1980, p. 429). Preiser (2002, p. 42) defined POE as ‘‘a process of systematically evaluating the performance of buildings after they have been built and occupied for some time’’, and Hadjri and Crosier (2008, p. 22) defined POE as a ‘‘process that involves a rigorous approach to the assessment of both the technological and anthropological elements of a building in use’’.

From an architectural perspective, the RIBA’s Research Steering Group defined POE as “a systematic study of buildings in use to provide architects with information about the performance of their designs and building owners and users with guidelines to achieve the best out of what they already have” (RIBA, 1991, p. 191). This definition corresponds to Preiser’s later perspective of POE from the other end of the procurement spectrum, namely facilities management that “POE performs as a diagnostic tool for the evaluation of building performance” (Preiser, 1995, p. 19). With more recent developments in POE have been focussed on building performance evaluation (BPE) and universal design evaluation (UDE) underlining a “more holistic and process-oriented evaluation” (Preiser, 2002, p.9), POE studies started to consider non-technical factors influencing the design and building of facilities (Hadjri and Crozier, 2009, p. 23).

As above, there is no definitive understanding or industry standard as to what POE actually is, but it is evident that POE is a process that involves a thorough approach to the assessment of both the technological and anthropological elements of a building in use. It is a “systematic process guided by research that embraces human needs, building performance and facility management” and maintenance (Hadjri and Crozier, 2009, p. 22).

2.1.2 Development of POE in the UK

The earliest POE in Britain was conducted by the RIBA in 1960s (Cooper, 2001). It was the study of the organisation, quality of service, and productivity of architectural practices, published as The Architect and his Office (RIBA, 1962). According to the study, it indicates that the final part of *Plan of Work*, i.e. Stage M: Feedback, should be undertaken by both architects and clients though inspecting completed buildings two to three years after final completion. It was deemed as "*the most cost effective way of improving service to future clients*" (RIBA, 1965). However, Stage M was deleted from the RIBA Plan of Work, due potentially to the financial problem (Lawson, 1980).

> *"The RIBA should gather and disseminate information and experience on user requirements . . . [and] greater attention should be paid by practicing architects and Schools of Architecture to the application of work study techniques to problems of this kind"* (RIBA, 1962, p.15).

The PROBE (Post Occupancy Review of Building Engineering) Studies were undertaken by CIBSE (Chartered Institution of Building Services Engineers) between 1995 and 2002, in collaboration with William Bordass Associates and Building Use Studies. It evaluated building performance of a great number of recently-built non-domestic buildings in the UK, via both occupant survey and energy survey methods. It indicated that the issue of 'performance gaps' wildly existed in the evaluated buildings, particularly between the predicted energy performance and the actual energy performance (Cohen et al., 2001; Bordass et al., 2004). The similar issue, i.e. 'the performance gap' was revealed in the Carbonbuzz project, conducted by CIBSE and RIBA, which is a platform for benchmarking and tracking energy use in projects from design to operation.

In 1998, the Construction Task Force published its report, Rethinking Construction, focusing on "*the scope for improving quality and efficiency in UK construction*" (Egan, 1998, foreword). Cooper (2001), who reviewed the POEs conducted in the UK since 1960s, highlights the importance of POE for a 'green' future.

> *"It has the potential to help focus attention on what has been identified as the most critical aspect of improving the sustainability of built environment – manging and up-grading the performance of the existing stock"* (Cooper, 2011, p.161).

2.1.3 Benefits and barriers to POE

- Benefits and purpose

In general, POE is deemed as a vital approach to evaluate the actual performance of a building, where the occupants' feedback can reveal design successes and failures which are not instantly noticeable, even to experts (Bordass et al., 2001). For the assessment of building performance, POE provides a method of collecting and distributing information that is of value to all stakeholders within a building life cycle (Preiser, 1995, 2002; Hadjri and Crozier, 2009). This corresponds to what Zimmerman and Martin (2001) claim that POE focuses on assessment of client satisfaction and functional "fit" with a specific space.

In addition to the value to stakeholders, POE can be used to validate occupants' real needs, improve fit between occupants and their buildings, optimise services to suit occupants, reduce waste of space and energy, reduce

ownership/operational expenses, and improve competitive advantage in the marketplace (Zimmerman and Martin, 2010). Wauters (2005) also confirms the value of POE within the facilities sector as a technique employed to aid benchmarking of the quality of services ranging from maintenance and cleaning to the provision of office furnishings.

According to Zeisel's (1981) proclamation that the design process should be cyclical in nature rather than simply being initiated and concluded in concurrence with a specific design project, POE forms a "logical final step" in this cyclical process, providing a knowledge base of "lessons learned" from users in completed projects which could then be utilised to either improve spaces in existing buildings or form a programming platform for future buildings (Zimmerman and Martin, 2001, p. 169).

Besides the above benefits summarised, a number of plausible benefits for conducting a POE are suggested by Whyte and Gann (2001), including:

- applying design skills more effectively;
- improving commissioning process;
- improving user requirements;
- improving management procedures;
- providing knowledge for design guides and regulatory processes; and
- targeting of refurbishment (Whyte and Gann, 2001).

Accordingly, "POE is the provision of valuable information to support the goal of continuous improvement" (Zimmerman and Martin, 2001, p. 169).

- Barriers

Based on several review studies of POE (Hadjri and Crozier, 2009;

Zimmerman and Martin, 2010), one of the barriers of POE is 'ownership' (Cooper, 2001). Although POE benefits both clients and designers, Cooper (2001) suggests that POE will remain "stunted" until issues associated with who is undertaking POE and who is commissioning and paying for POE can be resolved. As POE is not part of the standard procurement procedure, there is little incentive for the design team to add to the standard approach (Turpin-Brooks and Viccars, 2006), while "clients may well perceive their payment for the building product as inclusive of any 'testing' to ensure it is working correctly/efficiently" (Turpin- Brooks, 2013).

Another potential barrier to the development and widespread adoption of POE was identified by Vischer (2001) – defending professional integrity. In addition, Hadjri and Crosier (2008) suggest that professional liability and litigation also can act as barriers to building evaluations being carried out by architects, because "POE may uncover problems which may label the building as 'under-performing' and reduce the value of the building for the client" (Turpin-Brooks, 2013, p. 183).

Finally, a lack of training for architects in how to conduct POEs could be acting as a barrier to the widespread adoption of POE, corresponding to the potential problems raised by Vischer (2001), i.e. time and skill. Preiser (2001) suggests that POE training should be involved in the studio courses undertaken for architecture students so that they might become more familiar with methods of evaluation.

Based on the benefits and barriers to POE, it is clear that POE has been hardly undertaken for the RIBA Award-winning projects due largely to the limited budget as well as the 'ownership'. However, as POE can benefit not only

clients and building users, but also designers and the profession, it is meaningful to conduct POE studies for these award-winning projects, learning advantages and disadvantages for future reference.

2.1.4 From POE to BPE

Developed during the mid-1990s, building performance evaluation (BPE) typically focuses on supplying information gained through phased evaluation across a building's life-cycle into the next building cycle (Preiser and Vischer 2005). With the development of building evaluation, BPE has been deemed as a more holistic approach to POE (Cleveland and Fisher, 2014). With regard to this, Hadjri and Crosier (2008) express that ''POE has progressed from a one dimensional feedback process to a multidimensional process that, as an integrated element, can help drive the building procurement process forward'' (Hadjri and Crosier, 2008, p.22). In this evaluation framework, POE represents only one of six internal review loops (see Figure 2.1-1) (Preiser and Nasar, 2008).

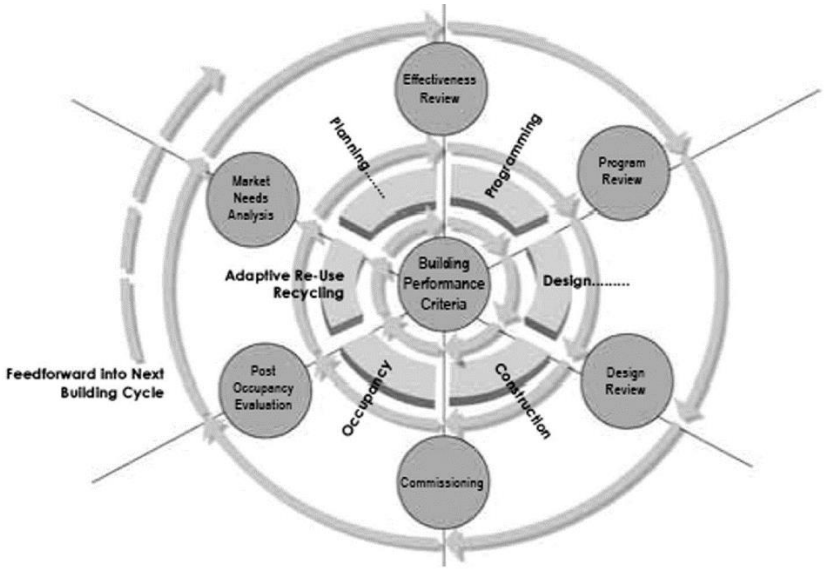


Figure 2.1-1: Building performance evaluation process model (source: Preiser and Nasar 2008, p. 90).

> *To improve the quality of decisions made at every phase of the building life cycle, i.e. from strategic planning to programming, design and construction, all the way to facility management and adaptive reuse… This means that not only facilities, but also the forces that shape them (organizational, political, economic, social etc.) are taken into account* (Preiser and Vischer, 2005, pp. 8–9).

Similar to one of the barriers of POE, i.e. cost, Leaman, Stevenson and Bordass (2010) state that evaluations of buildings using BPE have been relatively rare because of high cost. Nevertheless, they conclude that:

> *⋯ nothing beats case studies of named buildings backed by thorough data collection, benchmarked against a national sample, finishing with a list of lessons learned, preferably including reflections on the results by the parties directly involved, and especially the design team* (pp. 567–568).

2.1.5 Summary

The above overview of POE (including BPE) shows the purpose or justification of carrying out POE, the benefits and the barriers to the adoption of POE. It is reasonable to conclude that although POE potentially has a positive effect on building procurement over the last few decades, it has failed to be frequently undertaken and the potential benefit has not yet been realised (Hadjri and Crozier, 2009). However, in recent decade, there have been increasing number of examples of architects and clients, particularly among the elite firms, such as Arup and FCBs, that are beginning to take the notion of feedback seriously (Rouse, 2003).

With “POE has progressed from a one dimensional feedback process to a multidimensional process that can help drive the building procurement process forward” (Hadjri and Crozier, 2009, p. 31), it is necessary to promote POE adoption in the design industry. Accordingly, undertaking POE studies of well-designed buildings, i.e. award-winning projects, can benefit both the stakeholders and designers to learn from ‘exemplars’, hence increasing well-designed buildings. On the other hand, the lack of POE from mainstream architectural education has been pointed out as an obstacle by Hadjri and Crozier (2009). They suggest:

> *Fresh efforts are needed from the RIBA to highlight the need for POE awareness and need, therefore pinpointing the importance of research into human needs and building performance. Finally, more collaboration is needed between the architects and the construction professionals and particularly those involved in FM in general and building performance evaluation in particular* (Hadjri and Crozier,2009, p.31-32).

2.2 POE studies of schools

As mentioned previously in Section 1.3.1, the demand of quality schools with sustainable performance is increasing. To help with the design industry to deliver more well-designed schools, a series of POE studies have been undertaken by different organisations in the UK, including Partnerships for Schools (PfS), the original CABE, Building Use Studies and the Innovate UK. In the following content, an overview of the POE studies of schools conducted in the UK is shown with the corresponding findings.

2.2.1 CABE's school review

The original CABE had stepped up its support for Building Schools for the Future programme (BSF)[1]. In 2006, CABE assessed the quality of 52 secondary schools completed during the previous five years, before the BSF programme had begun. It was undertaken by the CABE's jury panel consisting of architects and lay assessors from the local authorities via walk-through evaluation and face-to-face interviews with the schools' end users. The school review was focused on the design quality of the schools as well as basic performance related to environmental sustainability. Twenty three of the 52 schools visited were assessed by design experts using an adapted form of the recently launched design quality indicator for schools (DQIfs), i.e. 111 indicators.

The statements were scored on a six-point scale, from 'strongly agree' to 'strongly disagree', depending on how much the enabler felt the statement was relevant to the school. The assessors could also score the statement 'do not know', if they felt there was insufficient information to score the school or 'not applicable'. This scale was then given a numerical value where strongly disagree equals to '0' up to strongly agree equals to '5'.

The review results showed clearly that the quality of school design was not good enough to fulfil the aspirations of BSF – "too few were inspiring, innovative, flexible and environmentally sustainable" (CABE, 2007). According to the review report, less than one in five of the schools audited was

[1] BSF programme was the last government's £45 billion programme to build or renew 3,500 secondary schools in the UK by 2020. The programme was to be scraped in 2010 due to financial deficit.

rated as ‘good’ or ‘excellent’ and half were “badly designed and poorly built” (ibid.). Although basic design aspects i.e. size, safety and accessibility went on well for most of the schools reviewed, basic issues of environmental sustainability such as the provision of natural daylight and ventilation were failed to be tackled in nearly all.

After the BSF programme initiated, CABE started another school design review programme to evaluate the design quality for BSF schools between 2007 and 2010, intending to ensure that design quality remains consistently high for all BSF schools. Designs were assessed against 10 criteria, ranging from creating a school that students and the community are proud of to putting the right strategies in place for environmental sustainability (see Table 2.2-1). Although all the design proposals of BSF schools were provided by professional designers, one of the CABE’s design review reports published in July 2008 described that nearly 80% of schemes reviewed by its schools design review panel were ‘mediocre’ or ‘not yet good enough’, implying that it was hard to support education transformation (CABE, 2008).

Table 2.2-1: CABE’s 10 criteria of a successful school design (source: CABE, 2010).

• Identity and context – making a school the users and community can be proud of
• Site plan – making the best use of the site
• School grounds – making assets of the outdoor spaces
• Organisation – making a clear diagram for the building
• Buildings – making form, massing and materials work together
• Interiors – creating excellent spaces for teaching and learning
• Resources – deploying convincing environmental strategies
• Feeling safe – creating a secure and welcoming place
• Long life, loose fit – creating a school that can adapt and evolve in the future
• Successful whole – making a design that works in the round.

CABE's chief executive Richard Simmons said that "some of the design lost the direction of being good education buildings from the beginning as they got basic wrong principles" (CABE, 2010, p.2). Some basic design flaws have been noticed through the CABE's school design reviews, such as badly natural-lit classrooms, less natural ventilation, overheating in summer, acoustic issue from noisy open areas and poor site design without accesses for disabilities, etc. Therefore, CABE provided a series of documents and regulations regarding how to achieve "design excellent" schools and improve the existing problems. After one-year improvement, 50% of the schools achieved 'good design' in the review in 2009. Although the results were better than previous ones, the CABE's report in 2009 pointed out that "only schools rated at least as 'good' allowed to go to planning as Partnerships for Schools (PfS) is preparing to introduce a minimum design threshold" (CABE, 2009).

2.2.2 PfS's POE studies of schools

Between 2010 and 2011, PfS carried out a POE study of 25 schools. The schools include 9 primary schools, 14 secondary/sixth form schools and two Special schools, all of which have benefitted from a new build or major refurbishment project (over £500,000). It intended to explore what contributes to a successful school environment and to recycle the lessons learnt back into the school capital programme. The POE was chiefly focused on three aspects: design, education, ICT and sustainability professionals; student and staff feedback; and environmental performance.

To ensure an objective and representative evaluation, the 25 schools were randomly chosen (from a long list of around 35) using the following criteria:

- Opened at least one year and constructed to comply with Building Regulations Part L 2006.
- The schools distributed across each of the three PfS operational regions of England.
- A balance of major refurbishment and new build projects.
- Reflecting a range of capital investment programmes and procurement methods including: BSF (Design and Build and PFI), Academies, One School Path finders, LA Devolved Capital and Voluntary Aided Capital.

Both qualitative and quantitative methods were conducted in this POE studies, including: a peer review by independent professionals – to assess the school buildings and grounds, considering design, education, ICT and sustainability; survey of student and staff – qualitative data gathered to assess how the building supports the school users; and an assessment of environmental performance – quantitative data gathered and compared against benchmark data, i.e. DfE's 'Energy and Water Benchmarks for Maintained Schools in England 2002-2003', to assess the in-use environmental performance.

For the peer review, the assessment was carried out by a PfS's jury panel consisting of four reviewers (with expertise in design, ICT, education and sustainability). The reviewers visited each school and recorded their views on a standard pro-forma based on the 10 established criteria and scoring system used for CABE Design reviews (refer to Table 2.2-1). Two site visits were undertaken by the reviewers to each school studied – the initial visit included a tour of the buildings and grounds and a meeting with senior staff, including the head teacher and building manager; and the second visit was to carry out workshops with the students and staff. Each reviewer gave a score (1 for 'poor', 2 for 'unsatisfactory', 3 for 'pass' and 4 for 'very good') against each of the 10

CABE headings and also for the school as a whole. These were consolidated into a single team score. Scores were moderated across all POE teams to ensure consistency.

According to the peer review results, 16 of the 25 schools evaluated were given an overall score of ‘pass’ by the PfS’s review teams, and nine were judged to be ‘very good’. However, a breakdown of the scores showed that nine of the schools were judged to be ‘unsatisfactory’ in terms of sustainability and two as ‘unsatisfactory’ in terms of ICT.

For the assessment of student and staff feedback, two steps were carried for data gathering, including paper-based questionnaires and workshops. In the questionnaires, the questions were all ‘closed’ with five options for answers to each question on a sliding scale from most positive response to most negative response with one ‘don’t know’ option. Questionnaires were completed anonymously by 30% of the students and 10% of the teaching staff at each school. Following the processing and analysis of the questionnaires, workshops were held at the school with a small sample of the teaching staff and students who completed the questionnaire. This gave the opportunity to explore in detail the issues raised. The workshops were structured through discussion of the most and least positive responses.

According to school users’ feedback, both students and staff generally showed high level of satisfaction with their school buildings and grounds. They responded most positively to questions of safety and the ease of movement around the buildings and grounds, while the least positive responses were related to summertime temperatures and ventilation, and the use of the outdoors for learning (other than for PE and sport), in accordance with the user

feedback. “The reasons that users felt hot or stuffy varied but were often linked to other issues such as acoustics, demonstrating inadequate integration of environmental design” (PfS, 2012, p.3).

With regard to the assessment of environmental performance, the two key environmental performance issues for schools were assessed in the Pfs’ POE studies: the environmental comfort of users in the learning spaces, particularly during the summertime; and environmental impact, measured through energy and water consumption and carbon production. Each school’s annual energy consumption was considered as a breakdown of the heating demand (gas/fossil fuels/biomass) and electrical demand which covers lighting, small power, equipment etc. The detail on the annual heating and electrical consumption was based on measured data obtained from the schools, collected through their monthly meter readings, utilities bills, or from records of energy use collected by the school’s LA energy manager. Energy performance and carbon performance results were compared to DfE’s ‘Energy and Water Benchmarks for Maintained Schools in England 2002-2003’, in $kWh/m^2/year$ and $kgCO_2/m^2/year$.

The energy analysis of the schools’ annual energy consumption showed that “most were performing poorly against benchmarks, especially in terms of consumption for heating” (ibid.). This was particularly the case for the secondary schools where all but one was consuming between 200% and 400% more energy than the benchmarks. Heating demand of the selected schools was found contributing by far the largest part of the energy demand in comparison to the electrical demand. For carbon performance, PfS’s carbon performance targets at the time of this study for PFI schools required a $27kgCO_2/m^2/yr$ benchmark to be met. The data collected from the one PFI school in this POE

shows the complex issue of carbon performance. While the carbon emissions off set by renewable technology meet the carbon performance target, the school still has one of the highest energy consumptions. “The carbon profile of a well-performing school should have both low energy consumption and low net carbon emissions, after taking account of the renewable energy used” (PfS, 2012, p.32).

The recommended courses of action, based on the lessons learnt from the POE, are summarised below.

- Making the most of space

Recommendation 1: Key messages about collaborative use of space and good premises management should be included in any future guidance design professionals. Schools should be encouraged to share their experiences about optimising their available space.

- Making the most of school grounds

Recommendation 2: Designers and school staff should consider the potential of the whole school site and share good practice in the use of outdoor space.

- Improving ICT – infrastructure and access

Recommendation 3: ICT infrastructure needs to support current use and future educational and technological developments. Good practice in the use of ICT should be shared between schools.

- Improving environmental performance-in-use

Recommendation 4: Schools should comply with the regulatory requirement to have a current DEC to help inform their actions to improve energy efficiency.

Recommendation 5: The DfE's current benchmark publication, 'Energy and Water Benchmarks for Maintained Schools in England 2002-2003', should be updated to include a statistical analysis of published 2010 DEC ratings for 5,000 schools. Schools should be encouraged to monitor and improve their annual performance against the benchmarks through a simple online toolkit.

Recommendation 6: The design of environmental strategies must be appropriate for a school, taking account of the fact that school staff do not have the expertise, time or budget to manage complex systems. Using a 'Soft Landings' type approach to the building contract, a phased or extended aftercare can help to fine-tune the building and train technical and non-technical school staff and students, to help ensure the building's performance-in-use is aligned to meet the users' needs, as identified in the design brief.

Recommendation 7: Evidence of performance-in-use should be collated to consider thermal comfort (particularly summertime overheating) and energy and carbon consumption (with detailed breakdowns of all energy uses such as ICT equipment, sports and security lighting and kitchens). This would help inform school climate change programmes and capital investment efficiency.

Recommendation 8: Evidence should be collated of performance-in-use of low carbon technologies to help inform school climate change programmes and capital investment efficiency. This should be aligned with CLG and DECC policies.

- Future of POE in schools

Recommendation 9: POE should become a normal part of the capital spend review process, using a streamlined methodology that takes account of the current government priorities, and considering the lessons learnt from this evaluation.

2.2.3 BSRIA's Soft Landings for Schools project

- Soft Landings

Soft Landings is the BSRIA-led process designed to help and support the construction industry and its clients to deliver better buildings and to make buildings perform radically better and much more sustainably (BSRIA, 2014). With the performance gap between design intention and actual building performance can emerge at any stage in a project, Soft Landings is designed to smooth the transition into use and to solve the performance gap.

> *Soft Landings starts by raising awareness of performance in use in the early stages of briefing and feasibility in order to set realistic targets and assign responsibilities. It then assists the management of expectations through design, construction and commissioning, and into initial operation, with particular attention to detail in the weeks immediately before and after handover. Extended aftercare, with monitoring, performance reviews and feedback assists building users to make better use of their buildings.*

> *Meanwhile, clients, designers, builders and managers can gain a better understanding of what to do next time* (BSRIA, 2014, p. 11).

According to BSRIA (2014), the five processes of Soft Landings are displayed as below:

"Stage 1: Inception and briefing

The time for constructive dialogue between the client, the designers and the potential constructors about intentions, performance requirements and stakeholder expectations. Embedding specific Soft Landings activities in the client's requirements and tender documentation, and setting aside budget for aftercare and post-occupancy evaluation. Effort should be made to get key specialist advice earlier than would be the norm - controls specialists, commissioning engineers, facilities managers; key subcontractors - catering, ICT, lighting, and controls integrators; nomination of Soft Landings Champions to drive the process forward; and reviewing past experience to inform design.

Stage 2: Design development and review

Brings the entire project team together to review insights from comparable projects and detail how the building will work from the point of view of the manager and individual user. Agreeing the energy strategy – and the metering and monitoring strategy – and the approach to commissioning, and ensuring they are regular items for discussion and covered in relevant tenders. Review the proposed systems for usability and maintainability, and reality-check as systems turn into actual installed products.

Stage 3: Pre-handover

Graduated handover enables operators to spend more time on understanding interfaces and systems before occupation. Revisit the outputs from earlier reality-checking decisions and ensure the suggested actions are in place. Ensure the BMS is set up the way the client intended – energy data reconciliation and data storage, and the energy monitoring software. Also ensure the metering is working properly and will deliver real insights into energy use.

Stage 4: Initial aftercare

The project team to be resident on site for between six and eight weeks to spot emerging problems and issues. Go walkabout regularly and chat to people, find out how systems are operating and whether they meet occupants' expectations and actual requirements. Adjust where necessary and report back. Help the asset managers understand what they've inherited. Measure and monitor – but don't rush to judgement.

Stage 5: Years 1 - 3 extended after care and POE

The period of longer-term, less intensive monitoring and support. Involves a series of aftercare review meetings – monthly to begin with, but could quickly become quarterly. Ensure that the energy monitoring is set up and working well. Conduct systematic post-occupancy evaluation no sooner than 12 months post-handover, repeated at 12 month intervals and culminating in a final project review at month 36" (BSRIA, 2014, p.11-12).

- Soft Landings for Schools project

To review how Soft Landings assist to deliver buildings with better performance, the Usable Building Trust (UBT) brought together a team of

organisations conducting a series of case studies to test the applicability of the *Soft Landings Framework* on school projects in progress and on schools that had been completed and occupied recently. The case study schools reached different stages of Soft Landings. Accordingly, the review was conducted to explore how *Soft Landings Framework* has benefited the selected school projects at different stages in terms of delivering better performance in use.

According to BSRIA (2014), the review results are "encouraging" (BSRIA, 2014, p.1). The approach of the Framework was found to help project teams take a more unified approach and to bring together previously disparate elements. The main findings of the school studies combined with the corresponding insights that have been gained are displayed in the following figures:



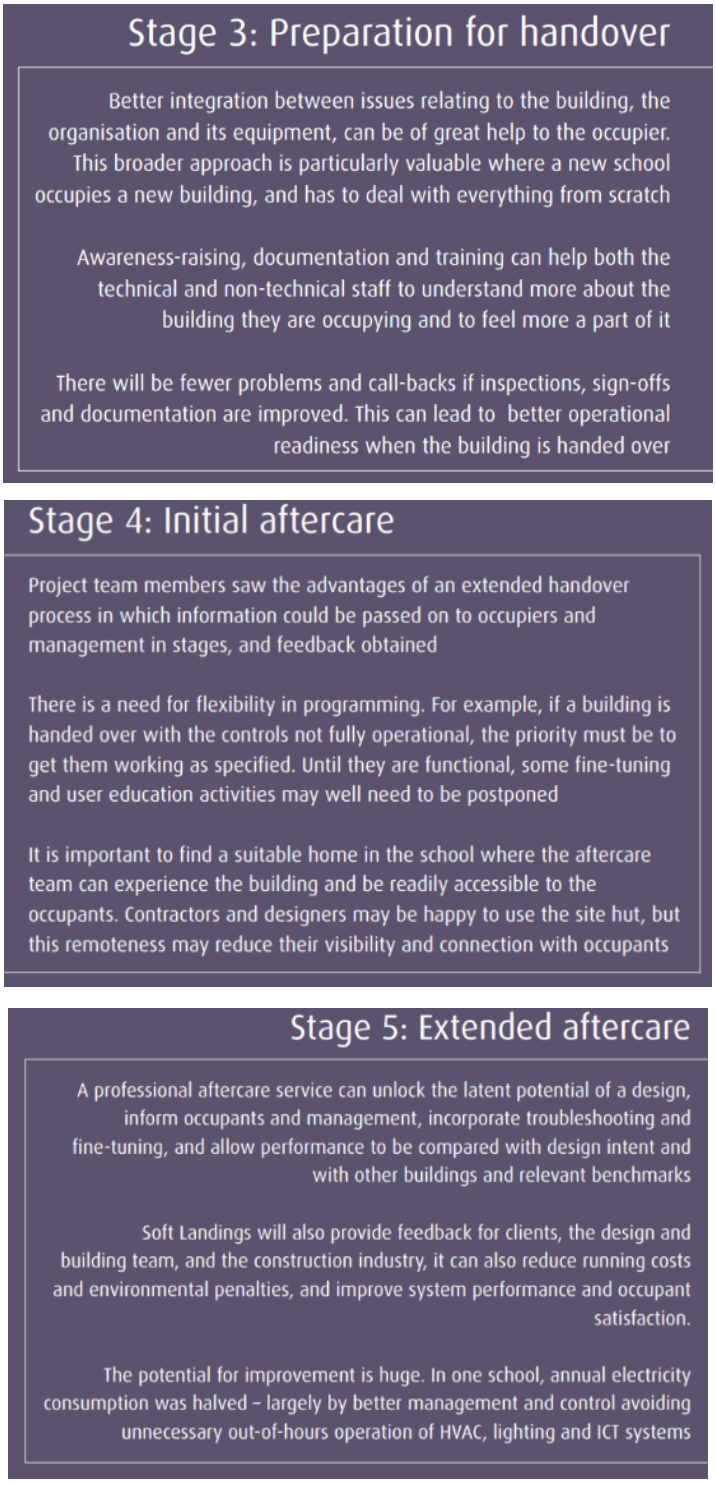


Figure 2.2-1: Valuable insights of the Soft Landings School studies (source: BSRIA, 2014, p.22-25).

2.2.4 Innovate UK's BPE programme for non-domestic buildings

In order to meet the Government's ambitious target of the reduction of 80%

carbon emissions by 2050, Innovate UK conducted a BPE study for over 100 buildings in the UK, with particularly reference to energy performance in use. There are 56 non-domestic buildings selected over the BPE portfolio as the research objects in which educational buildings took the largest proportion. The results for these buildings were exemplary, including five BREEAM 'Outstanding', 20 BREEAM Excellent, and two Energy Performance Certificates (EPC) A+ ratings. The study aimed to identify which strategies work well and what pitfalls to avoid. It also aimed to measure the gap between designers' objectives and what happens when occupants move in, and why this 'performance gap' is so common.

The main approach used in the BPE was to monitor accurately energy use in the selected buildings, implemented by using CIBSE TM22 methodology and worksheets. This approach was concerned as "a systematic approach to conducting an energy survey, recording findings, and estimating possible savings from changes" (Innovate UK, 2016, p.19). The measurements involved actual electricity and heating fuel use, where fuel use includes gas, oil, biomass and biofuel. The study normalised the data by floor area, so the energy figures show electricity or fuel use in terms of kWh per square metre per year.

The study found that it was difficult for projects to integrate new technologies, especially when configuring and optimising building management systems (BMSs). Some teams also had maintenance, controls and metering difficulties with their biomass boilers, photovoltaic arrays and solar water heaters. Additionally, one air-source heat pump (ASHP) had problems operating in cold weather. There were also problems with automatic window controls to support natural ventilation. This is partly inevitable when people start using new technologies, because installers lack experience fitting systems in different

buildings (Innovate UK, 2016). In addition to the use of environmental or renewable technologies, issues related to airtightness, problems with BMSs and unnecessary complicated controls were found having a great impact on the performance gap.

2.2.5 Summary of the POE/BPE studies of schools

According to the above overview of the POE/BPE studies of schools in the UK, the issue of the performance gap between design intention and actual performance was commonly found, indicating the need of more well-designed, energy-efficient and low-carbon schools.

CABE's school reviews exposed the lack of quality schools, while emphasising that design mistakes such as insufficient natural light and ventilation can still be found in present school design, hence designer's lack of considerations of building performance in school design. Both PfS's POE studies of secondary schools and Innovate UK's BPE for non-domestic buildings pointed out the issue of high energy performance of school buildings. Issues related to the use of environmental and renewable technologies, the use of BMSs and occupants' use of controls were proved having an impact on the performance gap. In addition, the PfS's POE studies suggested that streamlined POE should be widely used in the design industry to achieve the government's sustainable target. The probable contribution of Soft Landings Framework to delivering buildings with good performance in use has been partially evidenced in BSRIA's Soft Landings for Schools. The Framework was suggested to be went through from the inception and briefing of a project to the period after handover.

2.3 Summary of literature review

This literature review has overviewed the definition of POE, as well as benefits and barriers to POE. It is evident that POE can benefit both stakeholders to gather disparate information and designers to learn from the past. However, the ownership of conducting POE as well as the issue of liability can be the obstacle of promoting POE in the design industry. Even though with these issues, increasing POE studies have been undertaken by some design firms and organisations, intending to improve building performance while contributing to the relevant benchmarks.

Learning from the POE studies of schools in the UK, the need of quality schools with sustainable performance is urgent. POE studies can help both designers and school users identify existing problems and hence improving building performance. The performance gap between the design aspirations of designers and building performance in use has been deemed as a common issue in school buildings, which requires more attention of designers from the very beginning of design to the period after handover. Relevant training of POE is suggested to be promoted in studio courses for architectural students in order to increase the awareness of the design industry.

Chapter 3 Research methodology

In this chapter, firstly, a critical review of POE/BPE methodology and methods is provided by the author, exploring the advantages and disadvantages of different methods for assessing building performance in order to determine the specific approaches used in this research. The case study approach is then suggested as the most suitable approach to work with POE studies to this social science research project.

The second part of this chapter introduces the selection of the case study objects, explaining why the schools studied have been selected. A flow chart which clarifies the process undertaken of the whole research project is shown at the end.

3.1 POE Methodologies and methods

3.1.1 Methodologies

According to Preiser (1995) and Turpin-Brooks (2006), there are three levels of mythologies in the POE process. The level undertaken in POE will be determined based on the availability of finance, time, manpower and the required outcome, while the general approach to each level will involve planning the process, conducting the study and an interpretation of the results (Turpin-Brooks, 2006). The three levels as identified by Preiser (1995) and Langston and Ding (2001) are shown in Table 3.1-1.

For the different levels of POE, the corresponding methods employed are

various. Preiser (1995) associated indicative POE with quick walk-through evaluations which usually involve structured interviews with key personnel and group meetings with building users and inspections (Preiser, 2001; Cleveland, B. and Fisher K., 2014). For investigative POE, Preiser suggested that it was related to more in-depth analyses, such as interviews and questionnaires and across a number of buildings of the same or similar type (ibid.). In terms of diagnostic POE, it was normally used for highly valid research findings via relatively complex methods, considered as the most sophisticated of the methodologies (ibid.). Preiser "associated this approach with the evaluation of a number of comparable facilities from a broad range of technological and anthropological perspectives". In addition, he suggested that such research had the ''potential of being transformed into guidelines'' (Preiser 1995, p. 53).

Table 3.1-1: The three levels of POE (source: Turpin-Brooks, 2006, p.180).

Level of POE	Aims	Methods	Timescale	Comments
Indicative	Assessment by experienced personnel to highlight POE issues	Walk through evaluation. Structured interviews? Group meetings with end-users? General inspection of building performance? Archival document evaluations?	Short inspection period	Quick, simple, not too intrusive/disruptive to daily operation of building. Judgemental and overview only?
Investigative	In-depth study of the building's performance and solutions to problems	Survey questionnaires and interviews. Results are compared with similar facilities. Report appropriate solutions to problems	From one week to several months	In-depth/useful results. Can be intrusive/time-consuming, depending on the number of personnel involved
Diagnostic	Show up any deficiencies (to rectify) and collect data for future design of similar facilities	Sophisticated data gathering and analysis techniques Questionnaires, surveys, interviews and physical measurements	From several months to several years	Greater value in usability of results. More time consuming

3.1.2 Data collection methods

An overview of data collection methods in POE/BPE studies was undertaken to establish which would be the most suitable for this research. With regard to data-collection methods, to use multiple methods was suggested in order to ensure that the weaknesses of some methods can be compensated for by the strengths of others (Zimring and Reizenstein 1980; Turpin-Brooks and Viccars 2006; Cleveland, B. and Fisher K., 2014). In addition, Zimring and Reizenstein

(1980) realise that building evaluations are often required within tight timeframes so that temporal limitations can influence the choice of methods used.

Zimring and Reizenstein (1980) suggest the following methods for data collection: interviews, checklists, questionnaires, systematic observation, participant observation, critical incidents and archival record analysis. Based on these methods, Leaman et al. (2010) recommend a series of updated ones for data collection that include expert walk-throughs; measuring technical performance of building fabric, services and systems; assessing environmental performance; occupant survey questionnaires; structured discussion interviews with participants; and visually recording matters related to the above points (i.e. photos, video, thermo-graphic images). Among these methods, the researcher should select the suitable ones based on his/her research objectives and depths. In addition, the resulting data need to be compatible to previous studies in order to compare the results with past evaluations carried out on other buildings (Turpin-Brooks, 2006; Leaman et al., 2010).

Another recommendation regarding the selection of proper methods of data collection was proposed by Cohen et al. (2001). They suggest that the amount of time needed to both collect and analyse building evaluation data should be carefully considered when selecting or designing building evaluation tools, as it is possible to collect excessive quantities of data and hence leading to useless analysis (Cohen et al., 2001; Cleveland, B. and Fisher K., 2014).

As above, the use of a standard questionnaire, the assessment of environmental performance and the measurement of technical performance would provide the information that could be quantified and compared with previous studies.

Consequently, these methods can be used to collect data for assessing building performance of the RIBA Award-winning schools in this research. Nevertheless, it is noteworthy that with any qualitative data there will be a degree of bias due to the subjectivity of the respondent giving their opinions, attitudes and perspective (Cohen et al., 2000). In addition to this constraint, Turpin-Brooks, (2006) points out other potential limitations of using questionnaires, quoted as below:

> *"by using individual questionnaires with limited response answers, it would allow for individual attitudes whereas focus group meetings may be more biased towards dominant characters within the group*" (Turpin-Brooks, 2006, p.185).

When it comes to decide what type of questionnaires was to be used in this research that enables comparisons to be made to previous buildings that have been studied, there are two different questionnaires which were freely available at the time of the study and can be used for all types of buildings. They were the Design Quality Indicators (DQI) and Building Use Studies (BUS) questionnaire (free to research students). A comparison of the two questionnaires was made to establish the suitability for this study (refer to Table 3.1-2).

Design Quality Indicator (DQI) was developed as a 'thinking tool' by the Construction Industry Council (CIC) in collaboration with a steering group. It acts as an extension of the Rethinking Construction agenda for targeting, mapping, measuring and managing performance improvement in construction, developed explicitly to measure quality of design embodied in buildings (Gann et al., 2003). Learning from the comparison, the approach of DQI which

enables a large number of variables to be considered may lead to potentially low response rate.

Table 3.1-2: Advantages and disadvantages of the questionnaire techniques considered (source: Turpin-Brooks, 2006, p.185-186).

Questionnaire type	Section headings	No. of questions	No. of pages	Response categories	Critique
Design quality index questionnaire	1. Use 2. Access 3. Space 4. Performance 5. Engineering 6. Construction 7. Character and innovation 8. Form and materials 9. Internal environment 10. Urban and social integration	97	10	Strongly disagree to strongly agree with six possible responses and two additional response of do not know and not applicable	No mid point answer available. Many of the questions are not relevant to this study (e.g. construction process). Too onerous for the respondent – low rate of return predicted?
BUS questionnaire	1. Background 2. The building overall 3. Personal control 4. Quickness of response 5. Response to problems 6. Comfort 7. Noise 8. Lighting 9. Overall comfort 10. Productivity at work 11. Health 12. Your desk or work area 13. Travel to work (optional)	66 (excl. travel)	2 (excl. travel)	7 tier answer scheme, each with its own parameters, which is based upon the Bedford scale (e.g. for temperature, uncomfortable no. 1, to comfortable no. 7)	May come across as ambiguous, as tiers are not described. Interpretation could be 2 or 3 as slightly uncomfortable, or respondents could interpret the mid point no. 4 as slightly uncomfortable. Rating answer scheme allows for a richer response than a simple yes/no scheme

Develped along with the Building Research Establishment (BRE) (Cohen et al., 2000), the BUS Occupant questionnaire seeks to provide an economical compromise between the needs of respondents, data management, data analysis, statistical validity and question-answering ability (Cohen et al., 2001; Leaman and Bordass, 2001). It uses a relatively small set of key performance indicators which can be easily compared with other buildings within the BUS database. “It is based on what experience and statistical analysis has shown to be the most significant questions” (Turpin-Brooks, 2006, p.189). Accordingly, the BUS Occupant questionnaire is more suitable in this research in comparison with DQI, involing both the performace and design indicators. Not only

building performance perceived by the school users can be assessed, but also how ‘well’ the schools performed in practice in comparison with the similar type of buildings contained in the database can be considered.

By using the BUS Occupant questionnaires in this research, the respondents were asked to score each variable on a 7-point scale – typically from ‘unsatisfactory’ to ‘satisfactory’ or ‘uncomfortable’ to ‘comfortable’, where a ‘7’ would be the best score for the majority of the variables (Leaman and Bordass, 2001). Although some variables involved in the questionnaire are not necessarily required for this research project, such as the variables of ‘travel to work’ and ‘mode of travel’, a core set of key performance indicators (KPIs), including lighting, air quality, temperature and noise, cover the key parameters of building performance defined previously in literature review, and hence validity. A sample of the questionnaire can be found in Appendix 2.

- interviewee background (age, sex, etc.);
- the building overall (its design and how well it meets perceived needs);
- personal control (over heating, cooling and lighting);
- speed and effectiveness of response after complaints have been made to the management;
- temperature (in both summer and winter);
- air movement (in both summer and winter);
- air quality (in both summer and winter);
- lighting (natural light, artificial light and glare);
- noise;
- overall comfort;
- health;
- productivity at work.

Although the benefits of using the BUS Occupant questionnaires in the POE studies are stated previously, there are several noteworthy issues. Building users of 'green buildings' or 'well-designed' buildings (i.e. award-winning) have been considered more tolerant of building performance in use (Leaman and Bordass, 2007), and this could result in over optimistic feedback. In addition, highest level if satisfactory whereas in good buildings, occupant experience could be more than satisfactory (ibid.). To further explore the school performance in terms of handover issues, building operation, management and maintenance which are not involved in the BUS Occupant questionnaires, another surveys and interviews with the headteachers and site managers were to be undertaken (A survey sample can refer to Appendix 2).

3.1.3 Assessment methods of environmental and energy performance and the corresponding benchmarks

According to Leaman and Bordass (2007), building users may be more "*tolerant*" of 'green' buildings[1] for various reasons. As RIBA Award-winning buildings are awarded for their design excellence and sustainable considerations, it is reasonable to assume that some school staff involved in the POEs may provide optimistic answers. Thus, building performance evaluations (BPE) in terms of environmental and energy aspects is necessary to reveal performance from a quantitative aspect.

- Daylighting

Over the last fifty years, 'daylight factor' (DF) defined as the ratio of the

[1] The 'green' buildings referred to here were defined as the buildings that were "more sustainable in design intent, not necessarily in reality" (Leaman and Bordass, 2007).

internal illuminance at a particular point to the simultaneous outdoor illuminance under the same unobstructed sky condition has become the dominant indicator of daylighting performance, as well as 'uniformity ratio' (UR) that is a legacy of the DF approach. The standard that minimum 5% DF and 0.8 UR should be achieved in classrooms in schools has been used till now, according to BB 87 published in 1997. However, some doubts regarding the applicability of DF as well as notions of illuminance uniformity have been raised in recent studies, because the approach is founded on a measure of illumination only under the CIE (Commission Internationale de l'Eclairage) standard overcast sky (Mardaljevic et al., 2009; Nabil and Mardaljevic, 2005).

Nabil and Mardaljevic (2005) point out that the demerit of the DF approach is that it is lack of "*realism*" without taking account of the illuminance from the sun and non-overcast skies, "*so the daylight is invariant to building orientation*" (Nabil and Mardaljevic, 2005, p. 41). A new schema, named Useful Daylight Illuminance (UDI) that is determined from absolute values of time-varying daylight illumination for a period of a full year was developed by John Mardaljevic in 2006, in accordance with 'climate-based' daylight modelling (CBDM) that the (hourly) sun and sky conditions are founded on values from annual climate datasets (e.g. CIBSE TSY weather data). Several dynamic daylight metrics in accordance with the CBDM are proposed by many researchers, such as Daylight Autonomy (DA), Useful Daylight Illuminance (UDI), Continuous Daylight Autonomy (DA_{con}), Spatial Daylight Autonomy (sDA) and Annual Light Exposure (Reinhart, 2004; Nabil and Mardaljevic, 2005; Reinhart et al., 2006; Committee, 2012). When it comes to evaluating daylighting in schools, DA, sDA and UDI are often used. Hence, they are introduced as follows:

- Daylight Autonomy (DA)

DA, Daylight Autonomy, uses work plane illuminance as an indicator of whether there is adequate daylight in the space so that an occupant can work by daylight alone. It is defined as a percentage of the amount of time occupied per year when the illuminance level of a working plane in the space can be maintained at the required minimum illuminance level by daylight alone. The minimal illuminance level which can be directly taken from reference documents, such as CIBSE Environmental Guide (2006), is determined by the user requirements, the occupancy hours and the status of the blinds over an entire year. In the case of school buildings, the maintained illuminance level on the work plane in classrooms should be at least 300 lux, while the minimum illuminance of 500 lux should be achieved for art rooms, craft rooms and libraries (CIBSE, 2011).

DA was first mentioned by Association Suisse des Electriciens in 1989 as a Swiss norm, and then was revised by Reinhart and Walkenhorst in 2011. After that, Reihart further refined the concept of DA by combining it with a manual blind control model which can anticipate '*the status of movable shading devices at all time steps in the year*' (Reinhart et al., 2006). According to the criterion of the latest Baseline Design for Schools (BDFS) 2014, a minimal target of 50% DA is required for each learning space, sports hall and exam areas (EFA, 2014).

- Spatial Daylight Autonomy (sDA)

sDA assesses the balance of daylighting in the classroom from a *spatial* aspect. It is defined as the percentage of an analysis area that meets a minimal daylight illuminance level for a specified fraction of the operating

hours per year (IES, 2012). The standard threshold for sDA has been recommended as $sDA_{300/50\%}$ by the Illuminating Engineering Society (IES) of North America; this threshold represents the percentage of "*the calculated points across the analysis grid that meet or exceed the 300 lux value for at least 50% of the working year*" (IES, 2012, p2).

- Useful Daylight Illuminance (UDI)

UDI, proposed by Mardaljevic and Nabil in 2005, is a dynamic daylight performance measure also based on work plane illuminances (Nabil and Mardaljevic 2005; Nabil and Mardaljevic 2006). It is defined as the annual occurrence of illuminances across the work plane within a range considered "*useful*" by occupants (Nabil and Mardaljevic, 2005), neither too dark (<100 lux) nor too bright (>3,000 lux). The upper threshold is meant to discover moments when excessive daylight might lead to visual and/or thermal discomfort. The original UDI range was determined based on reported occupant preferences in daylit offices (Nabil and Mardaljevic 2005), ranging from the upper threshold of 2,000 lux to the lower threshold of 100 lux. With the adjustment made by Mardaljevic (2008), the latest range of UDI is between 100 lux and 3,000 lux.

On the basis of the UDI range (100 – 3,000lux), UDI results in four metrics, that is, the percentages of the occupied time of the year when the illuminance is less than 100 lux, i.e. UDI fell-short (or UDI-f); is greater than 100 lux and less than 300 lux, i.e. UDI supplementary (or UDI-s); is greater than 300 lux and less than 3,000 lux, i.e. UDI autonomous (or UDI-a); and is greater than 3,000 lux, i.e. UDI exceeded (or UDI-e). According to Mardaljevic (2006), UDI-f gives the percentage of daylight illuminance

lower than 100 lux, indicting daylight insufficiency; UDI-s gives the occurrence of daylight illuminance between 100 and 300 lux, and therefore additional artificial lighting may be needed as supplementary light source; UDI-a gives the frequency of daylight illuminances in the range 300 to 3,000 lux where additional artificial lighting will most likely not be needed. The last bin, i.e. UDI-e, is meant to detect the likely appearance of glare or thermal discomfort.

As per the BDFS 2014, UDI has been used as one of the chief metric to evaluate daylighting performance in schools. The output specification requires that a minimal target of 80% UDI (100- 3,000 lux) should be achieved in a year (working hours) for each learning space, sports hall and exam area (EFA, 2014).

- Air quality and thermal environment

Since the open-air school movement[2], the ventilation performance which is closely associated with indoor air quality (IAQ) and thermal environment has been considered as an essential to affect both staff and pupils' health and performance (Allard, 1998; Daisey et al., 2003). In the report *Displacement Ventilation for Improved Air Quality and Energy Use in Schools* published in 2006, the absentee rates of students were reported 60% declined after displacement ventilation was installed in Howell Township, New Jersey (Anon., 2006). On the other hand, as the thermal sensation also plays a vital role in the perception of comfort which is usually accompanied with air movement (Allard, 1998), it is reasonable to discuss these environmental parameters, i.e.

[2] To prevent the development of tuberculosis in children, the 'open-air school movement' was created in the early of the twentieth century, which required the schools to be able to provide fresh air, good ventilation and exposure to the outside.

ventilation, indoor air quality (IAQ) and thermal comfort as an integration.

According to an information paper published by the BRE in 2005, ventilation in schools is required to provide adequate fresh air for human respiration, to reduce and eliminate internal carbon dioxide (CO_2) concentrations and generated pollutants, such as carbon monoxide (CO), nitrogen oxides (NO) and fungi (DEFRA, 2001), as well as to remove excessive heat gains from classrooms for thermal comfort (BRE, 2005). However, insufficient ventilation was commonly found in classrooms, leading to high levels of CO_2, thermal discomfort and other pollutants (Lee and Chang, 1999, 2000; Daisey et al., 2003; Jones and Kirby, 2012).

Methods to adjust and control a building's air quality can be divided into two types: mechanical (forced) ventilation and natural (passive) ventilation (ASHRAE, 2005). Additionally, mixed mode (hybrid) ventilation containing both mechanical and natural components is used to achieve desired environment. Compared with mechanical ventilation, natural ventilation has been advocated in schools due to its benefit to both the user health and energy use. Typically, the energy cost of a naturally ventilated building is 40% less than that of an air-conditioned building (Energy Efficiency Office, 1993). Nevertheless, in is noteworthy that the application of natural ventilation could be limited by certain climatic conditions and other site constraints, such as noise and external pollution levels (Levermore, 2002). If it is under these conditions, careful ventilation design is required.

To help designers ensure ventilation efficiency in schools, the Education (School Premises) Regulations 1999 shows that minimal ventilation rates in teaching spaces is 3 l/s per person, while recommending that ventilation

approach used in any school building should be capable of providing an enhancement rate of at least 8 l/s per person (DEE[3], 1999). For indoor CO2 concentrations, ASHRAE Standard 62-2001 indicates that good air quality is likely to be achieved if the ventilation results in indoor CO_2 concentrations less than 700 ppm above the outdoor concentrations which are normally taken to be approximately 300 ppm (ASHRAE, 1999).

- Energy performance

The energy performance of buildings in England and Wales is regulated by Part L of the Building Regulations – *Conservation of Fuel and Power*. Since its introduction in 1965, Part L has been revised several times, incrementally tightening the requirements to improve energy efficiency of buildings. In the design process, energy performance prediction regarding compliance calculations is required to be conducted in accordance with Part L. This process is usually undertaken by engineers of a design team.

In order to regulate the energy performance of individual buildings, there are two additional regulatory requirements: Energy Performance Certificates (EPCs) and Display Energy Certificates (DECs). An EPC offers an energy rating for a building based upon the calculated CO_2 emissions (in $kgCO_2/m^2$ per year) for the building in comparison with a theoretical design to produce an Asset Rating. Similar to compliance calculations for Building Regulations, EPCs account only for the regulated loads whilst also relying on standard profiles for occupancy hours and patterns. The resultant certificate displays the rating on a scale from A (very efficient) to G (very inefficient), providing a record of the building's asset but not an estimate of their expected energy

[3] Department of Education and Employment.

consumption or carbon emissions. An EPC must be produced for all new buildings as well as those let or sold.

Different as an EPC, the DEC displays the operational rating of the building, based on the actual energy consumption over the preceding year. It must be produced for all non-domestic buildings with a useful floor area larger than 1,000 m^2 which is for public service and frequently visited by members of the public. The operational rating is displayed on a scale from A to G, calculated based on comparison against statutory energy benchmarks for the given building type (i.e. DEC benchmarks). The valid time of this certificate is only one year, and it calls for that every newly-built public building should have that certificate since 1st October, 2008. In addition, a DEC must be clearly displayed in a public area of the building, accompanied by an advisory report listing cost-effective measures to improve its rating.

According to Hogg and Botten (2012) and Menezes (2013), EPCs and DECs have no correlation and are not comparable, in spite of sharing the same rating scale. Nonetheless, such comparisons are commonly conducted in some research, raising the point that a favourable asset rating does not always happen in practice. Burman et al. (2012) show a clear example of this by analysing the performance shortfalls of an academy in North-west England with an asset rating of B and an operational rating of G. Such differences can cause misleading anticipations to clients and occupiers who are often unable to understand the distinction between both certification schemes.

Besides DECs and EPCs, CIBSE TM22 procedure is another method for assessing energy performance of an occupied building based on meter energy use (CIBSE, 2006). Three options are involved in the TM22 procedure to

assess the energy performance of buildings – Option A: Simple building assessment of the actual carbon dioxide emissions per unit floor area based on the metered energy use of a building of a single type with no more than two energy supplies (electricity and fossil fuel); Option B: General building assessment of the actual carbon dioxide emissions per unit floor area based on the metered energy use of a building or site which can have zones of different types and non-standard occupancy and energy uses; Option C: Systems assessment against benchmarks for the building systems (CIBSE, 2006, p.1).

For the three options, the corresponding purposes and procedures are slightly different. The TM22 method including a software implementation allows for different building types, the possibility of having a number of energy supplies (each of which can be from a wide range of standard, renewable and communal sources) and various service features. Thus, it forms the basis of well received initiatives including the PROBE investigations and Energy Consumption Guide ECG019: Energy use in offices.

- Energy benchmarks

The benchmarks used for DECs are published as CIBSE TM46 (CIBSE, 2008), based on a rationalisation and considerable simplification of values taken from many sources. CIBSE TM46 is divided into 29 categories representing chief building types (e.g. commercial buildings, educational buildings, residential buildings and swimming pools, and others), and are set at the median level for each category for annual use of electricity and of fuel thermal energy separately, assuming standard hours of use (in kWh/m^2). In May 2010, CIBSE commissioned a review of TM46 benchmarks based on DECs lodged since the inception to mid-February 2010 (Bruhns et al., 2011). Results suggested a good

correlation between the benchmarks and actual operational ratings for most categories. Additionally, the study indicated a common trend that more electricity and less fossil fuel is used in most categories in comparison with the benchmark values. According to Bruhns et al. (2011), this reflects the growth in electrical equipment usage in most buildings over recent years. With increasing internal heat gains from the equipment, as well as improvements in insulation, boilers and heating controls, heating demand is reduced.

In addition to the DEC benchmarks, there are DfE's 'Energy and Water Benchmarks for Maintained Schools' particularly for energy performance of school buildings, based on a broad range of energy-in-use data of the existing school building stock, including schools of two previous major UK school re-building programmes – Victorian and 1950s schools.

3.2 Case study approach

Robson (2011) indicates that the most commonly used methodologies related to social science research include ethnographic, case study, survey and action research. According to Robson (2011), a case-study approach is specifically helpful when a phenomenon needs to be researched in context. According to Yin (1994), case studies are one of the most common methods of conducting research in business and social science, allowing for "*complex multivariate conditions to be investigated*" (Yin, 2003, P.13). This is of particular benefit when evaluating 'building performance' of a scheme and exploring factors impacting on building performance, enabling a flexible research design. Although the scope of a case-study approach is somehow bounded and findings can rarely be generalised (Brown, 2008), it can "*provide rich and significant insights into events and behaviours, increasing the understanding of a*

particular phenomenon" (Menezes, 2013, p. 21).

A case-study approach was regarded as the most suitable choice to address the research objectives of this PhD project outlined in Section 1.4, as it allows for an empirical investigation of a contemporary phenomenon within its real-life context (Yin, 1994; Menezes et al., 2012).

3.2.1 Specific POE methods used in the case studies

POE including BPE was used as the primary approach in the case studies to evaluate actual building performance of the selected schools. Numerous methods were implemented in the case studies with the primary aim of investigating building performance of the selected cases and the key factors impacting on building performance. POE via questionnaires and interviews with the school users explored both the architectural design and the indoor environment of the selected schools from a qualitative aspect, while performance analysis via computer-based simulation and on-site data monitoring investigated building performance from a quantitative aspect. Each individual method addresses a different requirement for data collection or analysis. Table 3.2-1 summarises which methods were used in the case studies.

Walk-throughs were undertaken throughout the case study process, normally consisting of two to three-time on-site visits. At the early stages of the case study, the on-site visits provided opportunities for the researcher to observe and notice advantages and disadvantages of the building design as well as to obtain feedback from the school users. During the first visit, a relatively simple interview and a questionnaire derived from the *10 criteria for successful school*

design[4] (CABE, 2011) were carried out with the headteacher, investigating his/her level of satisfaction with the school's overall design quality and performance. During the second visits, interviews with the site/facilities managers were conducted. The interview questions were drawn up from the findings of the BUS Occupant questionnaires undertaken with the school staff, which looked for the potential reasons for the issues raised by the school staff from the survey. For the interviews with the site/facilities managers, information regarding building operation, management and energy performance of the schools was desired to be obtained.

Table 3.2-1: Summary of methods used in the case studies.

		Case 1	Case 2	Case 3	Case 4	Case 5
Case review	Information collection	√	√	√	√	√
	Interviews with design team	√	√	√	√	√
POE – occpant feedback	Walk-through visits	√	√	√	√	√
	Interviews with headteachers	√	√	√	√	√
	Interviews with site/ facilities manager	×	√	√	√	√
	BUS Occupant survey with school staff	√	√	√	√	√
BPE – performance analyses	Climate-based daylight analysis	√	√	√	√	√
	Luminance simulation	√	√	√	√	√
	Optivent calculation	√	√	√	√	×
	On-site data monitoring (T, RH)	√	√	√	√	√
	EPC	√	√	√	×	√
	DEC	√	√	√	√	×

The BUS Occupant questionnaires that evaluates satisfaction and comfort level

[4] CABE published 10 criteria for successful schools in 2011, which included 10 aspects related to design quality of schools in the UK. Details can be referred to in Chapter 2.

of the occupants regarding building design and building performance via a number of variables was undertaken with the school users. In this research, only the school staff, including teachers, administrators and service staff, were chosen as the interviewees of the BUS occupant questionnaires, as the feedback of children whose age under 11 was considered less reliable (Leaman and Bordass, 2001).

The evaluation regarding design quality of the selected schools focused on school appearance representing a school's identity and usability. The performance analysis focused on the four aspects defined as the KPIs for schools in accordance with the literature reviews in Chapter 2 – daylighting, ventilation efficiency and thermal comfort, and energy efficiency. The building performance evaluation results of each performance aspect were compared with the occupant feedback regarding the corresponding variables, in order to evaluate building performance in a comprehensive way.

a. Daylighting (climate-based daylight analysis, luminance ratios)

According to literature review, daylight sufficiency, daylight distribution and glare possibility were considered as the chief parameters contributing to daylight quality in schools. To analyse whether the daylighting strategies applied for the schools studied can support sufficient daylight as well as balanced daylight distribution, the climate-based daylight analysis (i.e. UDI paradigm) was conducted as the chief approach in the case studies, accompanied with the daylight factor approach. The UDI approach delivered predictions of time-varying illuminances of the space based on its location (i.e. geographically-specific climate data are used), orientation, and building configuration, taking into account of various sky conditions and sun positions,

and hence relatively realistic results.

For the climate-based daylight analysis, 3D models of the five schools were built in Autodesk Ecotect Analysis 2011[5] in accordance with the orientation of the schools and their surroundings. As learning space acts as key functional spaces of schools in which students and teaching staff spend most time, a number of classrooms with different orientations were identified as the key evaluation objects to represent daylighting performance of the schools studied. How many classrooms were picked from each school for the analysis was decided as per school size and spatial arrangement.

In the simulation process, DAYSIM[6], as the calculation tool in the climate-based daylight analysis, computed the hourly internal illuminances at each testing point within the selected spaces, using the hourly sky and sun conditions derived from the relevant CIBSE weather datasets Test Reference Years for every daylit school-hour in the year (i.e. where the irradiation is greater than zero – out of 1860 hours, Monday to Friday, 9 a.m. to 16 p.m.). The calculation points lay on the work-plane of each classroom (normally 0.7 m from the floor). The glazing type (i.e. the value of transmittance) and the interior conditions of the selected classrooms (i.e. the reflectivities of the walls, ceilings, floors and furniture) were set based on the current design. Detailed settings for the simulation can refer to each of the case studies.

[5] Autodesk Ecotect Analysis is a design tool for sustainable design analysis, which offers a wide range of simulation and building energy analysis in terms of thermal, daylighting and solar radiation factors, among others.

[6] DAYSIM, which was developed by Christoph Reinhart in 1998, is a RADIANCE-based daylighting analysis software which can model the annual daylight in and surrounding the building.

To analyse daylight sufficiency and daylight distribution in the selected classrooms, useful daylight illuminance (UDI) metrics – UDI fell-short (UDI-f: <100 lux), UDI supplementary (UDI-s: 100-300 lux), UDI autonomous (UDI-a: 300-3,000 lux) and UDI exceeded (UDI-e: >3,000 lux) – daylight autonomy (DA)[7] and spatial daylight autonomy (sDA) were calculated and compared with the relevant benchmarks, i.e. *Baseline Design for Schools (BDFS) 2014*. For the analysis of glare possibility, methods such as shading analysis via Ecotect and the calculation of luminance ratios in the field of view via Radiance were chosen to be conducted based on the POE analysis and the UDI analysis. Detailed analysis process can be found in the case studies. Design-related factors contributing to satisfactory or unsatisfactory daylighting in the schools were intended to be drawn from the daylighting analysis.

b. Ventilation efficiency and thermal comfort (Optivent calculation and on-site monitoring)

The majority of the schools studied are naturally ventilated apart from Chelsea Academy. In addition, cross-ventilation is used as the chief ventilation strategy in all the schools studied which are naturally ventilated. To evaluate whether the natural ventilation strategy works effectively to remove excessive heat gains from the schools (i.e. testing classrooms in the case studies) in summer, a quick calculation is adopted. The calculation programme is an Excel spreadsheet named 'Optivent' designed by Diaz and Ford in 1996 at BFA (Brian Ford Associates and Architects). It enables researchers to test the natural ventilation performance of a building with 'stack effect', and hence suitable for most of the cases studied. The calculation is resulted in air flow rates and air exchange per hour achieved in the testing space, which allows a

[7] Definitions of UDI metrics, DA and sDA can be found in Section 3.1.3.

comparison with the relevant environmental standards for ventilation in schools.

Due to the limitations of the equipment that could be used during the study time, another key indicator of ventilation performance, i.e. the internal concentration of carbon dioxide, was not assessed in the BPE studies. As many previous studies have proved that it is closely related to the productivity of the building users, the assessment of the indoor concentration of CO_2 should be involved in the evaluation of ventilation in schools in future studies. On the other hand, the Optivant programme can only provide rough results about whether the natural ventilation strategy employed works effectively to remove excessive heat gains under certain conditions, and normally restricted conditions. Therefore, it was simply used as a supplementary tool to verify the credibility of the occupant feedback regarding ventilation efficiency of the schools selected. For Chelsea Academy which is predominantly ventilated via mechanical ventilation, the analysis of ventilation efficiency can only rely on the occupant feedback via the BUS Occupant survey. This is another limitation of assessing ventilation performance in this research.

For thermal performance, the following parameters were measured during the occupied periods at the specified internal spaces: (a) dry bulb temperature (T) and (b) relative humidity (RH), measured via Tinytag data loggers[8]. The measurement was undertaken twice in a year – approximately four weeks in summer and four weeks in winter, respectively, investigating the efficiency of the ventilation and thermal strategies employed under different climatic conditions. Measurements were carried out with the sensors at a height of 1.1 metres near the glazed areas in each space, which corresponds to the height

[8] Tinytag data loggers are manufactured by Gemini Data Loggers based in the UK, and are specially designed for indoor temperature and humidity monitoring.

suggested in ISO 7726-1985 (Thermal environments- instruments and methods for measuring thermal comfort) for head level for a sedentary occupant. Measurements made every second were averaged over three-minute intervals. The spaces for on-site monitoring (i.e. classrooms, offices and staff rooms) were identified based on the occupant feedback of thermal environment of the schools. The results of on-site monitoring act as supplementary evidences to verify the credibility of the school users' feedback.

c. Energy performance (EPC and DEC)

As per the literature review, energy efficiency and annual carbon emissions are the essential performance parameters that should be assessed in the case studies. The TM22 method allows the assessment of energy performance of an occupied building based on metered energy use. For this research project, it requests detailed meter reading of each school studied for a relatively long monitoring period in terms of both electricity and fossil fuel usage. Thus, either monthly visits to each school studied or data recording from the schools' site managers would be required. This research study is a self-funded project conducted by the author only and hence research difficulties. As energy performance is not the primary indicator of building performance researched in this study, the TM22 method was not carried for assessing energy performance. Instead, DECs which indicate both operational energy efficiency and annual carbon emissions of buildings were chosen as an effective tool to investigate energy performance of the schools studied.

The DEC operational rating (from A to G) allows a comparison between the school's energy efficiency and the DEC benchmark for typical schools in the UK, indicating how efficiently the school performs in use. On the other hand,

as the issue of ‘performance gaps’ has been commonly found in previous studies (Bordass et al., 2004; Menezes et al., 2012), EPCs which provide predicted energy performance of buildings were also collected for the case studies, with the purpose of investigating whether these ‘well-designed’ schools performed as efficiently as anticipated.

3.3 The selection of the case study objects

The selection of the case-study objects was complied with three rules: validity, representativeness and comparability (Yin, 1994). According to the research scope of this PhD project (refer to Section 1.3.1), the RIBA Award-winning schools were firstly identified as the ‘general’ research objects, as the RIBA Award scheme has been acknowledged as the most reputable architectural award programme in the UK which evaluates design quality of architecture from various aspects – not only design-related factors, such as architectural expression and innovation, but also factors related to a scheme’s social, economic and sustainable impact.

When it comes to the specific selection of the award-winning cases, the author firstly identified 26 schools that won the RIBA Awards between 2008 and 2011, as it permitted at least the one-year occupation of the selected cases before the start of the case studies in 2012. This allowed the *validity* of the case studies, corresponding to the POE routines defined by Cohen et al. (2001) and(2007) that POEs such as the occupant surveys should be carried out at least one year after the occupation. Based on the 26 cases identified, five schools which won the RIBA Awards between 2008 and 2011 were chosen as the ultimate case study objects – Wellstead Primary School, Sandal Magna Primary School, St Luke’s CE Primary School, Minster School and Chelsea Academy. The

ultimate objects comprise three primary schools and two secondary schools. Although primary schools and secondary schools have different levels of complexity, the selection of both primary and secondary schools allowed two different built forms to be studied, and hence *diversity* and *comparability* of the selected cases. On the other hand, all the five schools are designed by experienced architectural practices with high reputation of sustainably architectural design in the profession. It is reasonable to assume that their works are mostly well-designed, and hence *representativeness*.

As this research project is a self-funded project conducted by the author within a four-year period, the number of the case studies undertaken is limited. The comparatively narrow database may lead to limited results. Nevertheless, the validity, representativeness and comparability of the case studies, to a certain extent, ensure the feasibility and scientific nature of this research project.

3.4 Overview of the methodological approach

The research project was undertaken as a 'thinking process' that allows the researcher to critically analyse the work carried out and make an action plan for continual progression (CICE, 2012). This approach is derived from O'Leary's cycles of research that consist of a process – "*observe, reflect, plan, act and observe…* " (Koshy et al., 2010), which has been also used by Menezes (2013) in her PhD project entitled as *Improving Predictions of Operational Energy Performance Through Better Estimates of Small Power Consumption*.

The flow chart in Figure 3.4-1 illustrates the key process of this research project, underlining the cyclical nature of the methodology undertaken. This process allowed for the five case studies to be carried out based on the

guidance derived from the review of literature, and also provided rational evidences to guide the direction of the research based on the key findings of the case studies. By carrying out this process, building performance of the selected award-winning cases were evaluated via the case studies, and a model that interprets the key factors impacting on building performance (i.e. influencing design quality) was established on the basis of the findings of the case studies. On the basis of the model developed, suggestions for designers to improve building performance and recommendations to the judgement of 'design excellence' in architecture were further provided, implementing the process of reconsidering 'design excellence' via building performance.

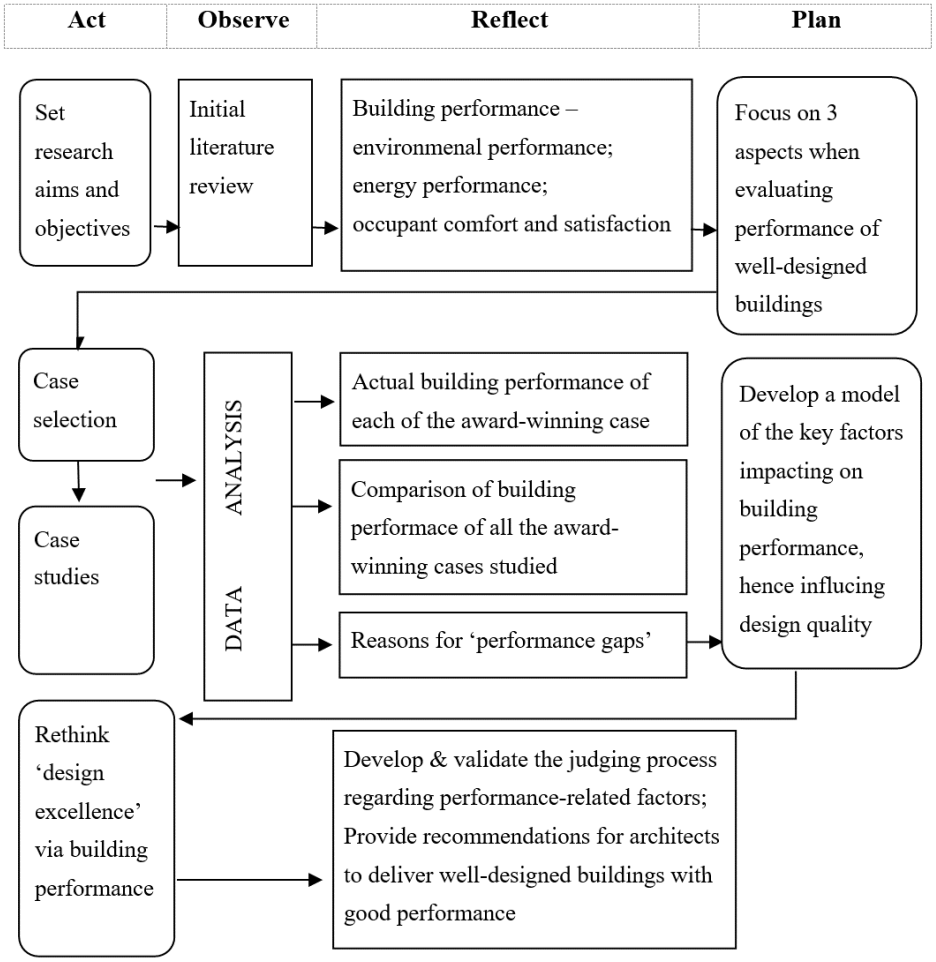


Figure 3.4-1: Research map detailing the process undertaken during the research project (source: Author).

Chapter 4 A pilot case study

Five RIBA Award-winning schools were selected as the case study projects in order to explore their building performance in use and the factors that may affect actual building performance. This chapter shows a detailed case study of one of the selected schools, i.e. Wellstead Primary School, including design-related information and performance-related results. It was considered as a pilot project to reveal the feasibility of the research methods employed and shows the basic findings.

Design-related information was collected from the interviews with the lead architect of the design team, introducing the design intent and the design strategies employed. The assessment of technical performance in terms of environmental performance and energy performance was undertaken via on-site data collection and computerised monitoring. For non-technical performance which reveals feedback from users, handover issues and building management, it was assessed via BUS Occupant surveys and interviews.



The view of Wellstead primary school (source: HCC Property Services).

4.1 Design information

4.1.1 Context

Wellstead Primary School is a primary one-entry form school located at Hedge End in Southampton, Hampshire, providing places for 210 pupils. Designed by HCC Architects, the school accommodates facilities and spaces for general teaching, sports and entertaining activities, and provides staff accommodation, and sanitary and service facilities. Some of the facilities can be shared by the community for after-hours use.



Hedge End, Southampton, Hampshire, UK
Latitude: 50.5 °N, Longitude: 1.2 °W
Percentage of heating required days (<16°C)
77.4%
Percentage of cooling required days (>26°C)
0.1%
Prevailing wind:
West (annual), southwest (spring and fall)

Figure 4.1-1: The location of Wellstead Primary School and the climatic information of Hedge End. (source: Google & CIBSE weather data 2005)

Since its completion in 2008, the school has received a number of awards for its architectural excellence as well as the provision of a good learning environment, such as the FX International Best Interior Design Award (2009) and the Solent Architecture Design Centre Award for Quality Place (2010). The RIBA Awards programme (2010) also recognised the school for its design quality two years after the school was built. The following citation taken from the RIBA Awards 2010 indicates the design achievement of the school highlighted by the jury.

"What sets this school apart straight away is its absolute clarity. A transparency on arrival gives views through a low glazed library space to a courtyard and playground set between two taller pitched roof forms that contain classrooms. This clarity is founded upon a collegiate typology that goes back to the monasteries that prefigured schools and colleges– an educational paradigm…" (RIBA Awards, 2010).



Figure 4.1-2: The site plan of Wellstead Primary School (source: HCC Property Services).

The school was designed in two separate linear forms with big pitched roofs. The separate building forms create different zones to manage various activities by preventing unnecessary interruption. For example, educational activities are separated with the communal activities in two parallel blocks, which consciously provides a relatively quiet and secure environment for general

teaching. A central courtyard is completed by a learning resource centre to the west, which is a so-called ‘library’, a glazed corridor to the east and two flat-roofed blocks to the south and north sides. Although the design of ‘courtyards’ can be often found in many Hampshire school designs, this one was specifically designed as a ‘relaxing’ space for the school staff only.

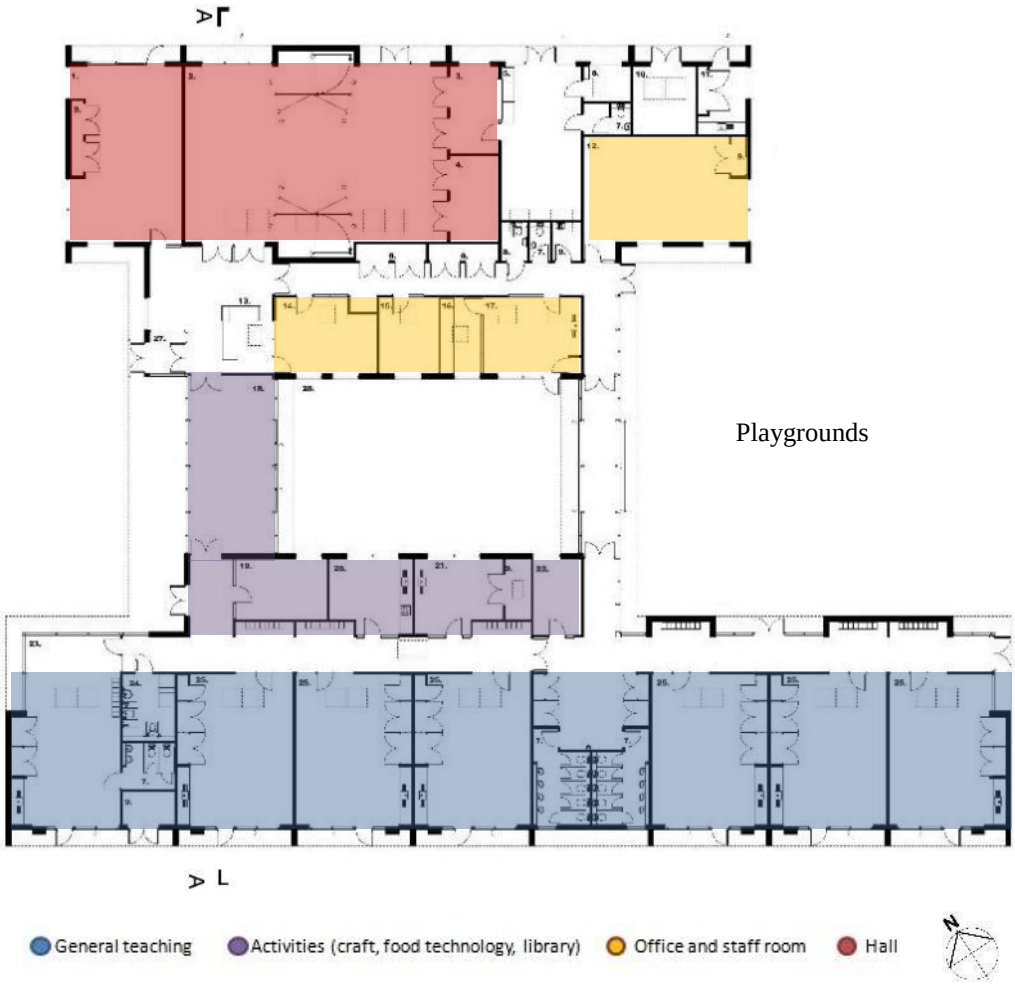


Figure 4.1-3: The plan layout of the Wellstead Primary School (source: HCC Property Services).

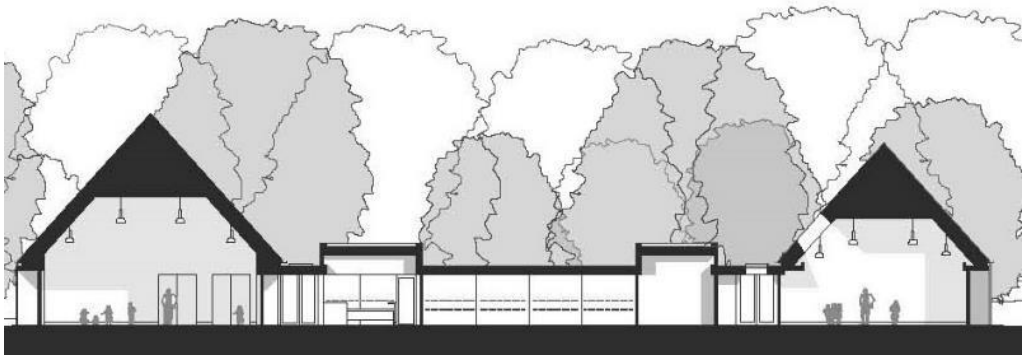


Figure 4.1-4: Section A-A of Wellstead Primary School (source: HCC Property Services).

4.1.2 Design intent

The brief provided by the Local Education Authority [1] was to supply a "*sustainably designed one form entry*" for Hampshire (SCALA [2], n.d.). According to the brief, the following detailed targets were set (see Figure 4.1-5).

- Creating a strong sense of place and community identity
- Allowing the community in but providing a secure and safe environment
- Inspiring learning and attendance
- Encouraging development of a child's sociability and well-being
- Offering longevity and attractive environments with adaptable delightful structure
- Being energy efficient and minimising carbon emissions

Figure 4.1-5: Design intent of Wellstead Primary School (source: HCC Architects)

[1] Hampshire County Council's Children's Services Department.

[2] SCALA is a collaborative organisation of public sector architects and related professionals committed to assisting its members in achieving the highest possible standards in the development, design, construction and management of the public sector estate for the mutual benefit of their employers.

4.1.3 Design process

To achieve the above targets, the design team used a series of design approaches at different design stages, including precedent studies, site analysis and performance prediction, and others. Figure 4.1-6 displays the detailed approaches used through the design process, based on the interview with the lead architect (Liam Presley) and the in-house engineers. The participants, i.e. architects, engineers and end users, who were involved at different stages of the process, were also indicated in the figure.

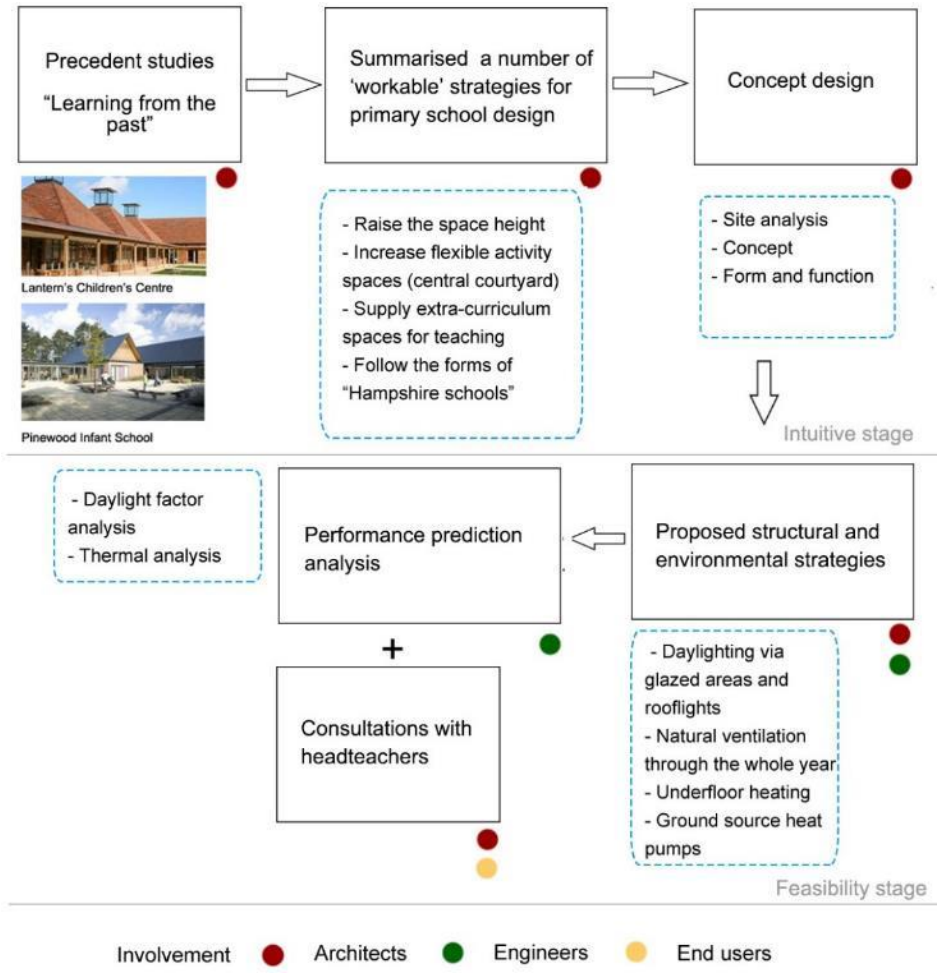


Figure 4.1-6: Design process of Wellstead Primary School (source: Author).

At the early design stages in which design decisions are relatively 'intuitive'

(Trebilcock, 2007), the architects learned from the precedent studies, and summarised a number of 'workable' strategies for the design of Wellstead Primary School with a few adjustments depending on the site constraints and brief requirements (Liam Presley, interview, 9 February 2012). After the conceptual design at the 'intuitive' stage, the HCC design engineers then joined the architects to discuss a series of design issues relevant to structural and environmental strategies. The in-house engineers, Boardman stated that 80% of the strategies with regards to environmental aspects, such as lighting, ventilation and heating, were resolved by the engineers at the very early stage due to the budget limitation. Simple performance prediction analysis was conducted by the engineers. The remaining 20% was adjusted at the later stage according to the cost as well as the influence depending on the early performance predictions (Neil Boardman[3], interview, 9 February 2012).

The environmental strategies applied for Wellstead were mainly "*driven by compliance issues*" to meet the minimum requirements of relevant guidance and building regulations, such as the CIBSE Design Guide A24 and Building Bulletin 101 (ibid). Boardman (2012) indicates that passive strategies in terms of daylighting, ventilation and passive solar heating were proposed by the in-house design engineers, acting as primary environmental strategies for Wellstead, and some energy-saving technologies were suggested by the design team in order to reduce carbon emissions. Details of the environmental strategies employed are shown in the following section.

The feasibility of most of the passive strategies proposed were assessed by the engineers at the 'feasibility' stages. Regarding the efficiency of other strategies,

[3] Neil Boardman is the HCC design engineer, who was responsible for the main engineering issues of the Wellstead Primary School, working with Liam Presley.

such as the acoustic layout for the school as well as the artificial lighting efficiency, it was evaluated by some external engineering consultants, i.e. RHB Partnership and Arup.

In spite of the involvement of the professionals, the end users of buildings always play a key role in the design process and also have key role in affecting the final implementation of buildings (Devlin, 1996). However, in the case of Wellstead Primary School, the absence of the end users in the design process, i.e. the school staff and students, was pointed out as a design "*limitation*" of this project by Presley (Liam Presley, interview, 9 February 2012). Presley expresses that "*it was difficult to enquire specific requirements and demands from the school occupants as well as the community at the design stage*" (ibid). Thus, the design team faced a challenge in adopting the "*inclusive people-based approach*" which they had used for school design in the past, and had to utilise for school design, and had to adjust some design strategies at the very late constructional stage after the head teacher had become involved.

4.1.4 Design strategies

A series of strategies involving architectural, social and environmental considerations were proposed by the design team to achieve the design targets. To understand how the design team pursued its achievement of these goals, this section describes the intent and the implementation of the strategies from the 'big' scale to the 'detailed' scale, according to the information provided by the architect as well as on-site observation.

- Site and orientation

The school is located at the tip of a green lung (see Figure 4.1-1), sitting

between two groups of residential housing. It chiefly orients toward the southwest and the northeast. Although the optimal orientation, i.e. south-north, has not been achieved, the current orientation intends to maximise opportunities for daylighting, passive solar heating and natural ventilation, while it responds to the site's shape and can benefit from the prevailing wind from the west (see Figure 4.1-2) (Liam Presley, interview, 9 February 2012).

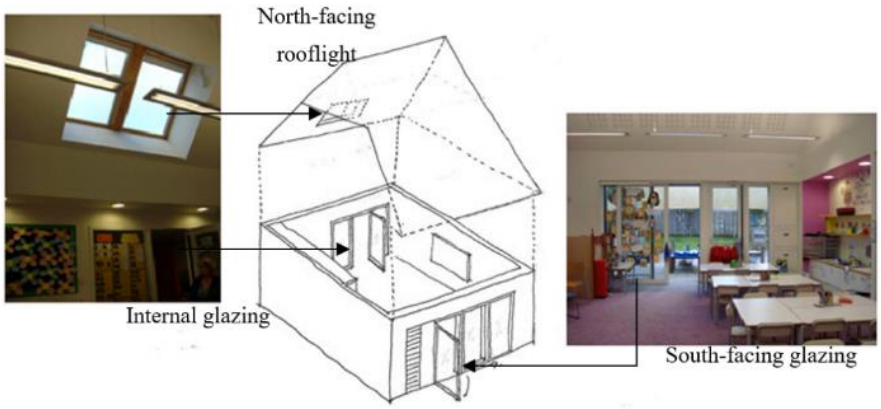
- Daylighting and electric lighting

Although the optimal orientation has not been achieved, the school was designed to be daylit primarily to reduce the amount of energy used for electric lighting by receiving benefits from the architectural form, and fenestration system, as well as the interior colour rendering.

To maximise daylighting opportunity, the architects enlarged the glazed areas within the design of Wellstead Primary School, such as full-height glazing design and rooflights on pitched roofs. External shading, i.e. overhang eaves (900mm) and a few external folding canopies above the southern playing areas, was provided for the southwestern classrooms. Adjustable blinds were also settled internally within all glazed areas to allow adjustment from the occupants internal curtains were also installed (See
Table 4.1-1). Although larger accesses were provided for daylighting by this glazing design, it is noteworthy that approximately one-third of the vertical glazing in classrooms and the office space is below general working task levels (i.e. one metre), which may not work effectively in optimising daylight while increasing heat loss.

Table 4.1-1: Daylighting design for Wellstead Primary School

- Daylighting design for classrooms



- Daylighting design for the hall, the head teacher's office and the staff room



- Shading system for the southern classrooms



In terms of electric lighting, it is used as supplementary source for lighting in the school. To reduce energy used for electric lighting, all the electric lighting

in functional spaces, such as classrooms and offices, has adjustment sensors which can be manually operated to modify the internal lighting environment based on the occupant demands. Movement sensors are linked with circulation spaces which intended to minimise unnecessary energy use.

- Natural ventilation

The school was designed to be operated in a natural ventilation mode in all year round. It is primarily controlled by the Building Management System (BMS) depending on the indoor temperature, and also allows occupants some personal control of thermal conditions based on their sensations within the indoor environment. Ventilation panels with acoustic louvers were installed in classrooms for air exchange in the winter months. For the other spaces, e.g. offices, library and the staff room, single-sided ventilation is permitted by glazed partitions that can be opened. Diagrams illustrating the ventilation modes in different seasons can be seen in Figure 4.2-12, Figure 4.2-13 and Figure 4.2-14.



Figure 4.1-7: Ventilation panels in classrooms for air exchange (source: Author).

According to the *Notes to Accompany Building Regulation Submission* (2007) provided by Presley, the school was designed to achieve an Air Permeability

Rating of 5 $m^3/h/m^2$ at 50 Pa to meet the ventilation provisions set out in Approved Document F, and every window was designed to be fitted with trickle ventilators to provide minimum background ventilation in winter.

- Heating systems

The architectural form permits two southwest-facing elevations to take advantage of passive solar heating opportunities. The large and tall glazing on the south-western facades allows solar radiation to warm the interior spaces during cold months, particularly classrooms, offices and the staff accommodation. To minimise heat loss in heating seasons, the design team selected quality bricks for external walls with 60mm insulation inside, and double glazed units combined with thermally broken frames were installed for external glazing and doors. In addition, the mechanical engineer calculated the U-values of certain building constructions, such as pitched roofs, glazed doors and external walls, among others, in order to retain the thermal efficiency of the building. Detailed U-value information of chief constructions is presented in Table 4.1-2.

Table 4.1-2: Material information of the main construction. (Source: HCC Property Services)

Construction	U-value (W/m^2K)
Pitched roofs (classrooms and hall)	0.18
Flat roofs (general)	0.18
External walls (general)	0.22
External glazing doors generally thermally broken aluminium (outer) and timber (inner)	1.8
Rooflights (pitched roofs)	1.8

Instead of radiators, the school is under-floor heated, and the heating system is primarily controlled by the BMS via wall-mounted thermostats provided in

each room. Hot water for heating is primarily supplied by five ground-source heat pumps buried underneath the hard play area, and is also provided by gas-fired hot water generator with a pre-feed solar hot water cylinder.

- Acoustics

To minimise the impact of noise and unwanted sound for teaching activities, the sloping ceiling of classrooms that the highest point reaches five metres allows a relatively large volume to reflect sound, and the acoustic ceiling with holes on the top collaborates with the sloping ceiling to absorb noise. Carpet throughout the school also acts as a noise absorber. Additionally, acoustic louvers were installed on the outside of the ventilation panels on the south-western façade to block out the noise from the M27 motorway to the west.



Figure 4.1-8: Acoustic ceiling of classrooms (left) and external acoustic louvers (right) (source: Author).

4.2 Building performance analysis

The analysis of the building performance in terms of environmental and energy performance was conducted in this study via on-site data collection and computer-based simulation. Three chief environmental parameters were

examined: daylighting quality, ventilation performance and indoor thermal comfort. In addition, energy performance of the school reflected by its DEC rating, annual energy consumption and annual carbon emissions was compared with the benchmarks for primary schools in the nearby areas so as to assess its energy efficiency.

As this chapter shows a pilot case study, detailed process of the analysis and how the relative methods used for different analysis are displayed clearly in the following sections. For the rest case studies, only the evaluation results, i.e. technical performance and non-technical performance, and the corresponding analyses are presented in Chapter 4 and 5. The relevant analysis materials can be found in Appendix 3, 4 and 5.

4.2.1 Daylighting performance

To assess daylighting in the school, a 3D model of the school was built in Autodesk Ecotect Analysis 2011[1] in accordance with the orientation of the school and its surroundings for the simulation. A classroom facing the southwest was chosen as the key evaluation object to represent daylighting performance of the school (see Figure 4.2-1).

[1] Autodesk Ecotect Analysis is a design tool for sustainable design analysis, which offers a wide range of simulation and building energy analysis in terms of thermal, daylighting and solar radiation factors, among others.



Figure 4.2-1: The selected classroom for daylighting analysis (source: HCC Property Services).

To evaluate daylight sufficiency as well as daylight distribution in the selected space, climate-based daylight analysis was used as the chief approach for daylighting analysis. The hourly weather data were derived from the weather file of the CIBSE Test Reference Year (TSY) for Southampton (50.5 °N, 1.2 °W). UDI metrics, i.e. UDI-f, UDI-s, UDI-a and UDI-e, as well as DA[2] and sDA were calculated as key parameters to indicate daylighting performance of the classroom. According to the latest daylighting requirement in *Baseline Design for Schools (BDFS) 2014* that UDI should be achieved in at least 80% of the working year for all learning spaces and sDA should be no less than 50% (EFA, 2014). On the other hand, the luminance level of major task surfaces in the selected classroom was assessed in order to investigate the possibility of visual discomfort. The evaluation was implemented by on-site observation and computer-based simulation.

The dimensions of the selected classroom are shown in Figure 4.2-2. The southwest façade which acts as the chief daylight source has glazing which is 2.2 metres high starting from the floor and 4.6 metres in width, supplemented with the rooflight facing northeast. The reflectivity of the walls, ceilings, floor

[2] Definitions of UDI metrics and DA can be found in Chapter 2.

and overhangs were set to be 0.5, 0.7, 0.5 and 0.7, respectively. In the simulation process, all the glazed areas were modelled as double glazed windows with 0.64 light transmittance, corresponding to the 24 mm toughened and laminated glazed units installed in the school.

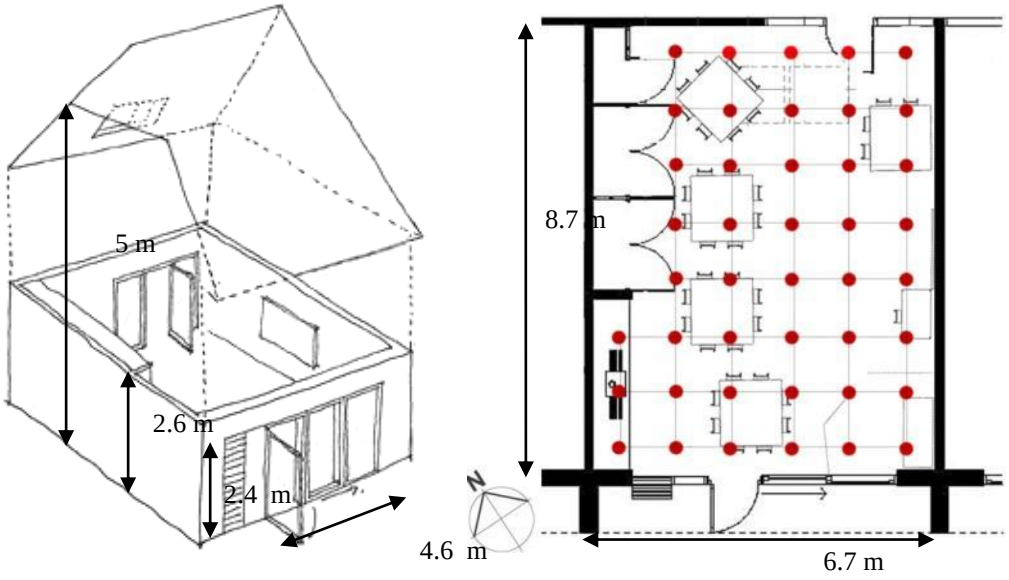


Figure 4.2-2: Classroom model with dimensions (source: Author).

For the simulation, an analysis grid of 43 calculation points was evenly distributed across the working plane (height 640mm for pupils' desks) of the classroom (see Figure 4.2-2). The distance between the walls and the boundary points in the grid was 0.5 metre, and the distance between consecutive points in both directions was 0.95 and 0.96 metres, respectively. Based on the hours during which the school was occupied i.e. 9 a.m. to 16 p.m., the total number of illuminance values computed was 1560 daylight hours*43 points= 67,080. In addition, occupant behaviour regarding blind control was considered during the simulation process. It set the mode of occupant behaviour as 'passive' to evaluate the 'design risk' that, in the passive mode, the building users will not pull down blinds to protect against direct sunlight.

The first scenario was to investigate whether or not the current architectural design for classrooms, i.e. the orientation of the school (southwest), the design of the fenestration system and the shading strategies (without external shading devices) can provide sufficient daylight for general teaching activities.

- Daylight autonomy (DA) and spatial daylight autonomy (sDA)

Referring back to the definition of DA in Section 3.1.3, it represents the numbers of annual daytime hours that a selected point in a space is above a specified illuminance level. Although (Reinhart et al., 2006) points out that the internal illuminance levels between 100 lux and 3,000 lux are "*useful*" for people to work with, most of the relevant environmental criteria, such as *CIBSE Environmental Design Guide* and *BB 90*, have suggested the illuminance of 300 lux as the minimum level for general teaching activities and office work in educational buildings. As the school was designed to achieve the environmental criteria mentioned above, for the calculation of DA in this study, the value of 300 lux was specified as the minimum illuminance target level. Hence, the value of DA_{300} is represented as a percentage of annual daylight *working hours* (i.e. between the hours 09:00-16:00) where a given point on the working plane in the classroom exceeds 300 lux.

Using the time-varying illuminances derived from the Southampton climate file, DA_{300} was calculated at each of the 43 calculation points on the working plane in the classroom. The simulation results are displayed in the following false colour maps (Figure 4.2-3), expressed in terms of the percentage of the working year.

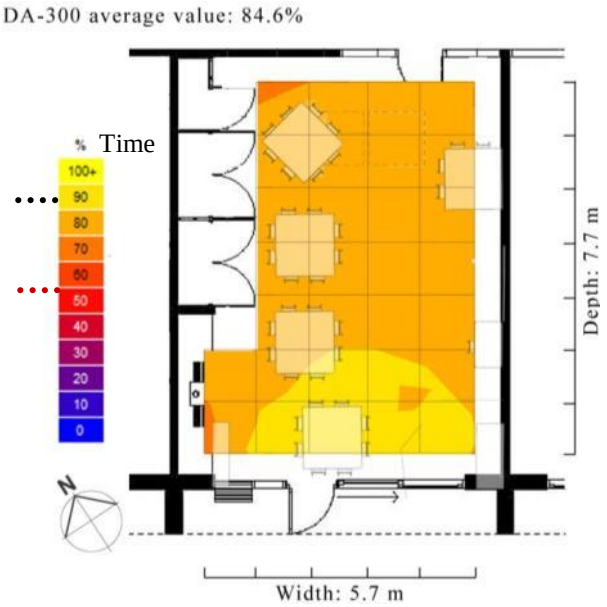


Figure 4.2-3: DA Isolux Contour map of the classroom (source: Author).

Reading from the isolux contour map shown on the plan in Figure 4.2-3, DA near the southwest glazing (within 2 metres) to the centre of the classroom drops from 100% to 80%, and the minimum values occur in the northern and western corners. The average value of DA reaches nearly 85%, indicating that, on average, the area under analysis in the classroom can receive at least 300 lux in 85% of the daylight working hours. It is therefore reasonable to assume that the classroom can generally achieve adequate daylight in most of the daylight working hours without the support of artificial lighting.

Whilst DA was used to evaluate daylight from a *time* factor, spatial daylight autonomy (sDA), which replaces the metric of Uniformity Ratio (UR), assesses the balance of daylighting in the classroom from a *spatial* aspect. According to $sDA_{300/50\%}$ recommended by IES (2012), the calculated points across the analysis grid that meet or exceed the 300 lux value for at least 50% of the working year. For the selected classroom, the value of $sDA_{300/50\%}$ is greater than 95%, demonstrating that nearly the whole working plane can receive at

least 300 lux over half of the time during the working year, which is also evident from the 3D graph of DA in the classroom (see Figure 4.2-4).

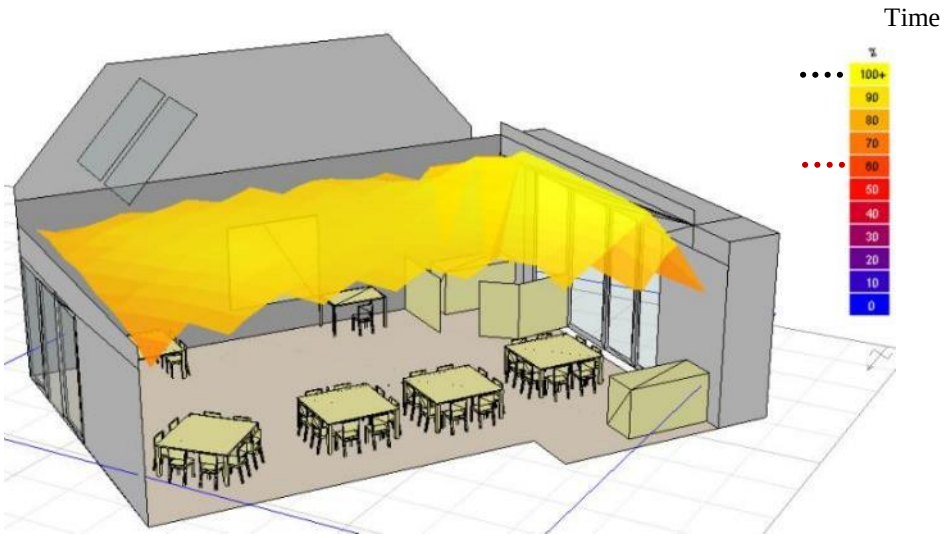


Figure 4.2-4: 3D graph displays the DA distribution in the classroom (source: Author).

Combining the results of DA_{300} and $sDA_{300/50\%,}$ it can be deduced that the design of the fenestration system of the school can assure daylight sufficiency in classrooms for general teaching activities. However, DA and sDA can only calculate the percentage of time/area that meets or exceeds the target illuminance level (i.e. 300 lux), but cannot predict the amount of time when excessive illuminance (i.e. greater than 3,000 lux) is present. Referring back to the previous POE results regarding daylighting, excessive daylight and glare from the sun and sky were raised by the school users as daylighting issues in classrooms. Thus, further study was conducted to evaluate whether the issue of excessive daylight does exist and, if so, how it affects teaching activities.

- The UDI metrics

The same illuminance data used to determine DA were re-processed to calculate the occurrences of four UDI metrics in the working year, i.e. UDI-f

(i.e. < 100 lux), UDI-s (i.e. between 100 and 300 lux), UDI-a (i.e. between 300 and 3,000 lux) and UDI-e (i.e. greater than 3,000 lux)[3]. Similar to DA, these metrics also examine the levels of daylight illuminance on the working plane at a horizontal level in the working year, but better reflect whether daylight insufficiency or excessive daylight exists or not.

According to the simulation results, the average value of UDI (i.e. between 100 lux and 3,000 lux) is 87.9%, which corresponds to the daylighting requirement in *Baseline Design for Schools (BDFS)* that UDI should be achieved in at least 80% of the working year for all learning spaces (EFA, 2014). Hence, to a large extent, we can assume that the design of the fenestration system for the classroom is able to provide useful daylight illuminances on the working plane at most times of the working year.

The graph in Figure 4.2-5 shows the results of the UDI analysis for the classroom, where each line in the graph represents the relevant results of a UDI index as if a line had been drawn down the centre of the room from the external window to the back wall. It can be seen from the graph that the values of UDI-a are maintained above 80% over half of the working plane indicating that, over 80% of the working year, the daylighting provided by the glazing design is adequate enough to support common teaching/learning tasks without supplementary artificial lighting. In addition, the introduction of the secondary glazing (i.e. the rooflight and the intermediate glazing) has been highlighted as it ensures the maximum values of UDI-a at the maximum values at the back of the classroom, and hence prevents uneven daylight distribution in the classroom.

[3] The definitions of the latest UDI metrics can be referred to in Chapter 2.

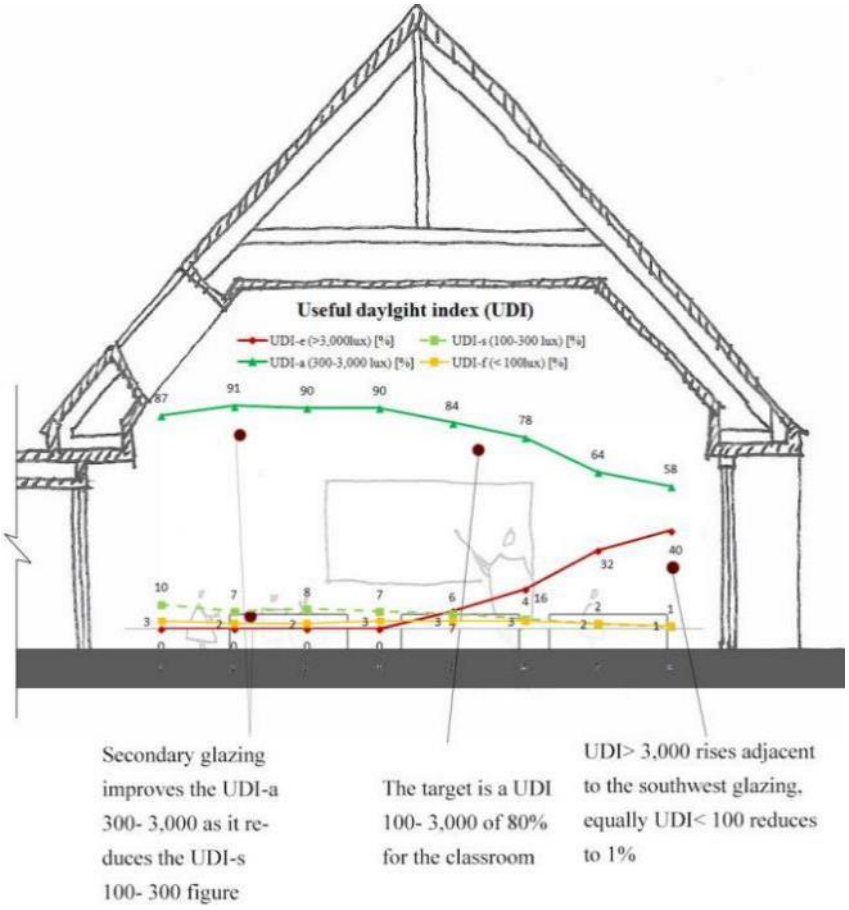


Figure 4.2-5: UDI index of the classroom shown on a section (source: Author).

The values of UDI-a, however, clearly fall from the centre of the room to the southwest glazing, and the minimum values (i.e. 58%) occur at 1.5m distance away from the glazing. It is evident from the corresponding 3D false colour map of UDI-e (refer to Figure 4.2-6) that this is due largely to UDI being exceeded (i.e. >3,000 lux) in the vicinity of the southwest glazing, and that this occurs up to 40% of the working year.

Visual performance (e.g. reading and writing) decreases when light reflects off task surfaces, particularly for the surfaces with high reflectivity, such as books and drawing boards. Based on the above UDI analysis, the illuminance values of the desk surfaces in the vicinity of the southwest glazing can exceed 3,000

lux up to 40% of the working year. It can therefore be deduced that the pupils who sit within this area may suffer visual or thermal discomfort (or both) because of the glazing design.

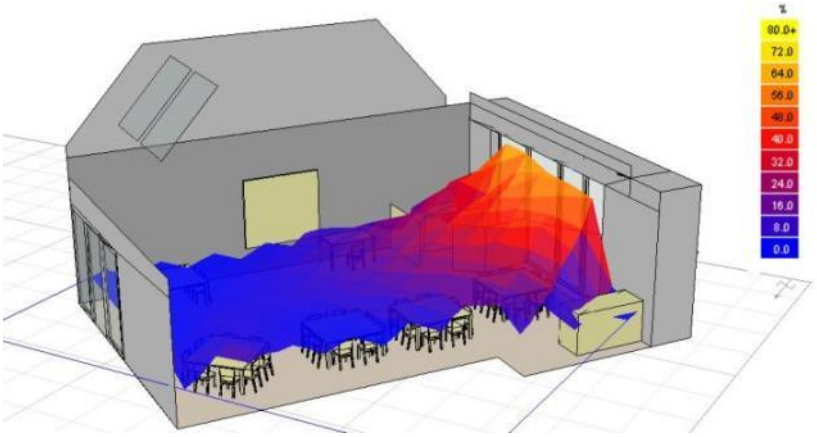


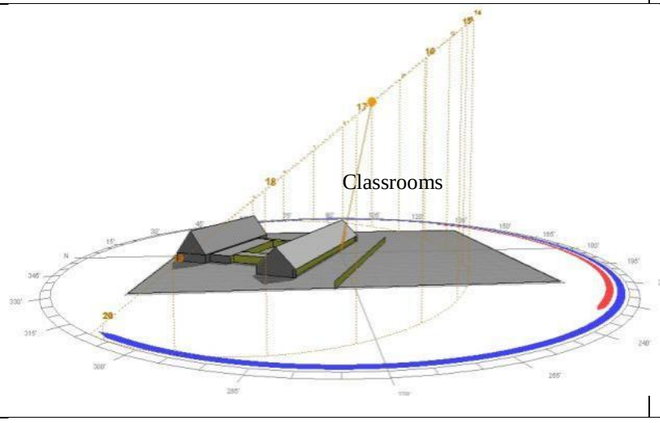
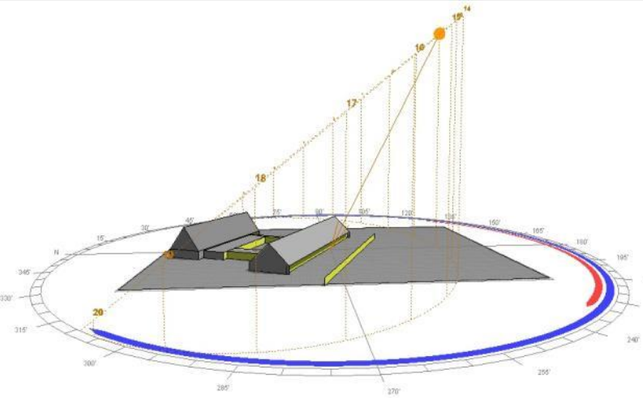
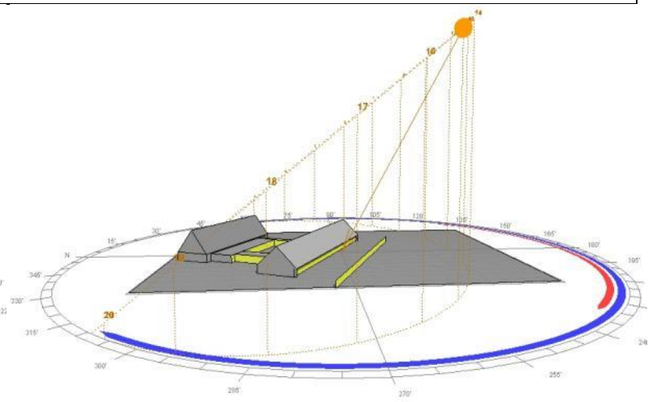
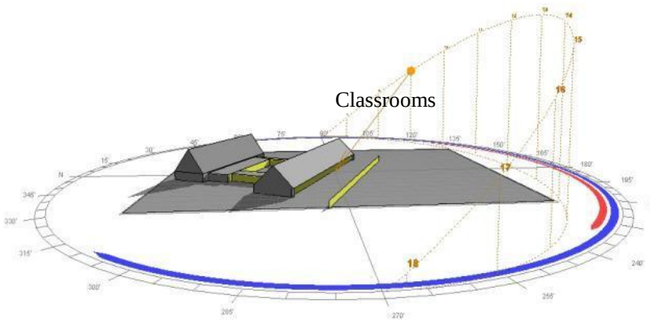
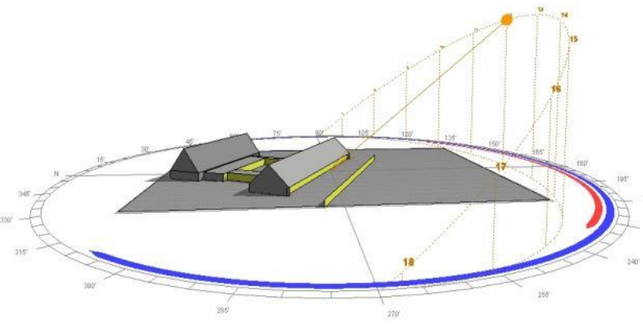
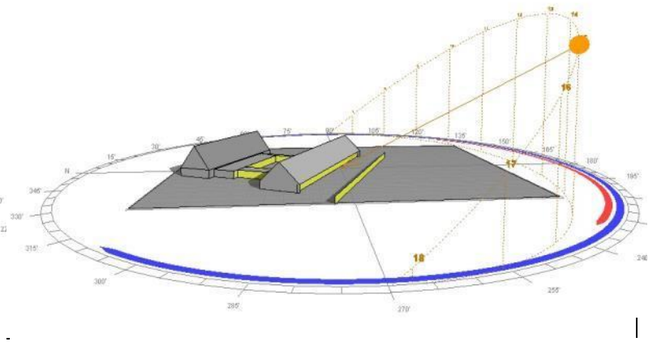
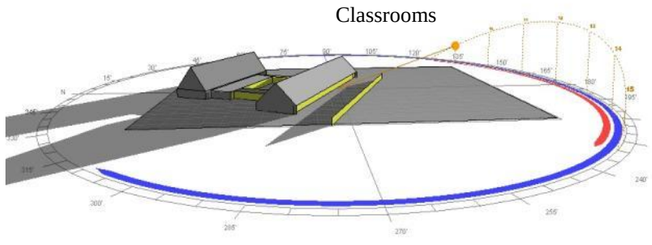
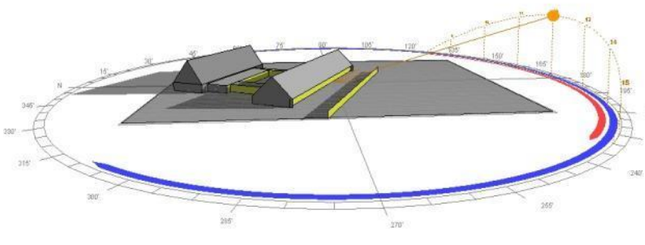
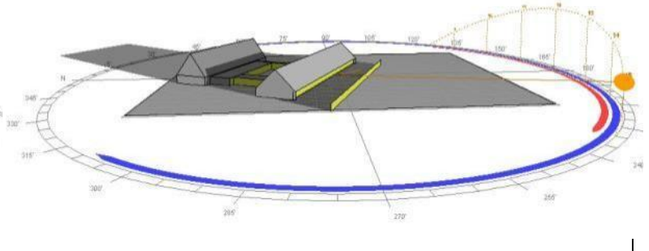
Figure 4.2-6: The 3D false colour maps of UDI-e in the classroom (source: Author).

- Glare possibility and luminance ratios

To explore whether or not sunlight can enter classrooms directly, thereby causing glare problem or visual discomfort, a solar analysis was conducted in Ecotect based on the location and orientation of the school, using the same weather file data for DA and UDI calculations. For the solar analysis, Ecotect calculated solar angles at nine specified moments in a year, i.e. 9:00 a.m., 12:00 p.m. and 15:00 p.m. at the summer solstice, the equinox and the winter solstice[4]. The bright yellow areas in Table 4.2-1 represent the elevations of the school that can obtain solar radiation from direct sunlight. It can be seen from the table that direct sunlight can enter classrooms via the southwest glazing at the summer solstice at 15:00 p.m., the equinox between 12:00 p.m. and 15:00 p.m. and the winter solstice from 9:00 a.m.to 15:00 p.m., respectively.

[4] The specified moments were defined based on the school timetable and their representatives of different climatic conditions.

Table 4.2-1: Shading analysis of the school.

	9:00 a.m.	12:00 p.m.	15:00 p.m.
Summer solstice			
Equinox			
Winter solstice			

In summer, direct sunlight can cause glare or overheating problems. According to the solar analysis, the introduction of the overhangs (900 mm) only blocks summer sunlight before noon (i.e. between 9:00 a.m. and 12:00 p.m.), rather than working properly when solar radiation is much stronger in the afternoon (i.e. between 12:00 p.m. and 15:00 p.m.). To a certain degree, it corresponds to the design guide in *BB79: Passive Solar Schools;* that overhangs over 300 mm do not create "*a significant benefit*" for shading or improving daylighting (DfEE, 1994). Foldable canopies installed externally are capable of blocking undesired solar radiation in the summer months (see Figure 4.2-7), although daylight sufficiency in classrooms could be affected.

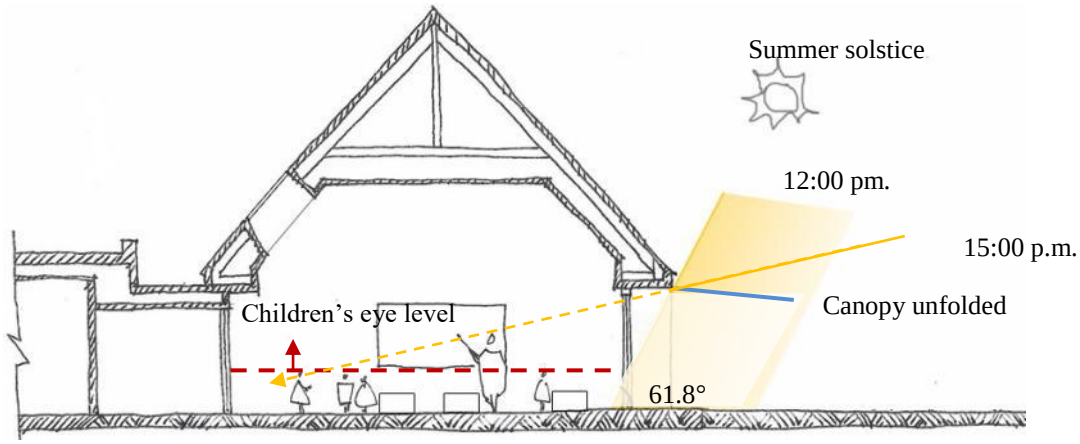


Figure 4.2-7: Shading analysis at the summer solstice: with external canopy (source: Author).

In the winter months, light-permeable blinds were attached internally to the southwest glazing to prevent glare while admitting solar heat gain (see Figure 4.2-8). However, a photo (Figure 4.2-9) taken on-site at the first visit to the school (i.e. at 15:00 p.m., 9 February 2012) shows obvious reflections off the desk surfaces in a classroom. In the photo, blinds for the southwest glazing were partially pulled down to block direct sunlight, but one piece of the glazing which acts as the fire exit for the classroom did not have blinds attached due to

security considerations. Because of the design of the glazed fire exits, direct sunlight can penetrate into classrooms in winter month, which can cause glare.

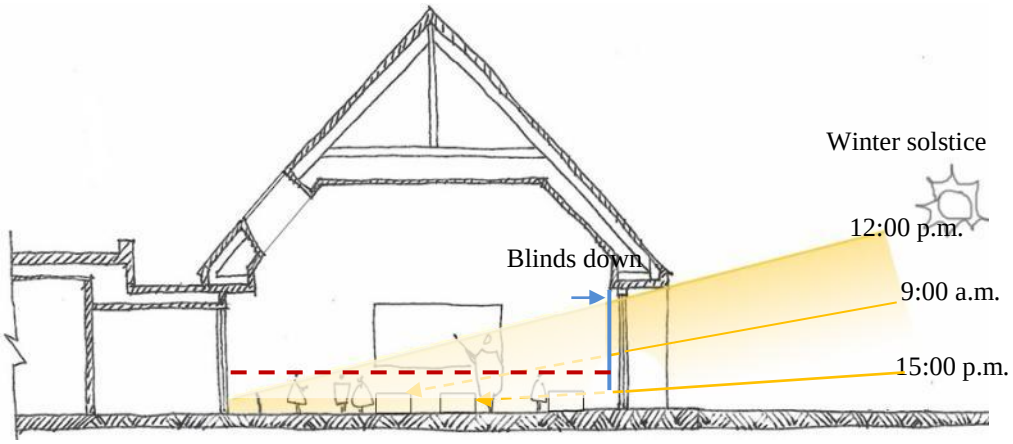


Figure 4.2-8: Shading analysis on winter solstice: with blinds (source: Author).



Figure 4.2-9: Obvious reflections appear off desk levels in a winter afternoon (source: Author).

The previous UDI analysis and on-site observation has clarified the risk of glare and visual discomfort at a horizontal level in classrooms. Except for high rates of illuminance and reflective surfaces, the contrast between the task and the surroundings can also lead to visual impairment. Luminance ratios in the field of view are usually considered as indicators of visual discomfort. In order to assess whether teaching/learning activities relevant to vertical surfaces, e.g. interactive whiteboards and walls, are affected by the glazing design, a further evaluation in terms of the luminance ratios of a whiteboard to the surroundings

was conducted in Radiance.

For the simulation, an observer's position was set in the centre of the classroom (4 metres away from the whiteboard), and the view route started from the view position at pupil's eye level (1 metre above floor) directly to the vision task. Based on the daylighting theories produced by Egan (1983), Robbins (1986) and Flynn et al. (1988), the cone of vision for task is defined within 10°, and a visual cone of 60° and 120° is defined for the immediate and far surround, respectively (i.e. meaning 30°/60° above and below the line of sight) (see Figure 4.2-10). Generally, the rule of thumb for luminance ratios in the observers' field of view should be within the range of 1:3:10 (Hopkinson et al., 1966), but some previous studies suggest that much higher luminance ratios can be tolerated when windows can be seen within the lighting visual display terminal (VDT) areas (e.g. even up to 1:50), if the patches of bright luminance that remain are around or less than 5% of the entire field of view (Newsham and Veitch, 2001; Sutter et al., 2006; Altomonte, 2008). In this case, the observer has relatively limited access to the glazing on both side walls, so we can assume that higher luminance ratios could be accepted[1].

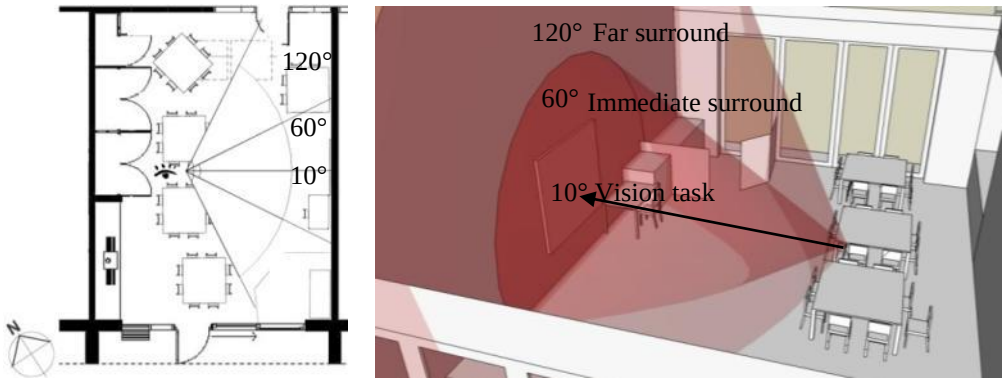


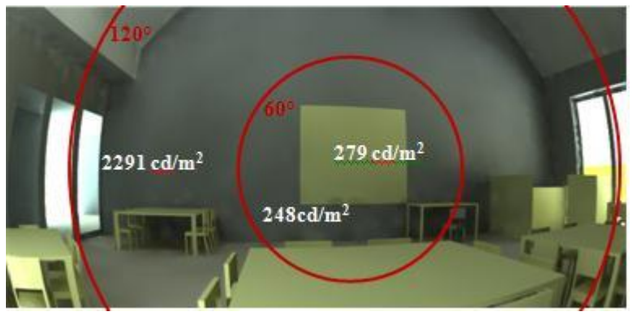
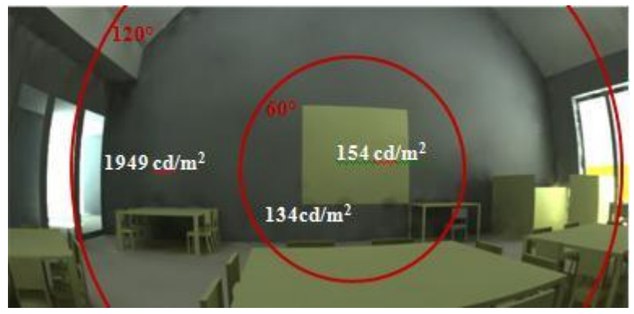
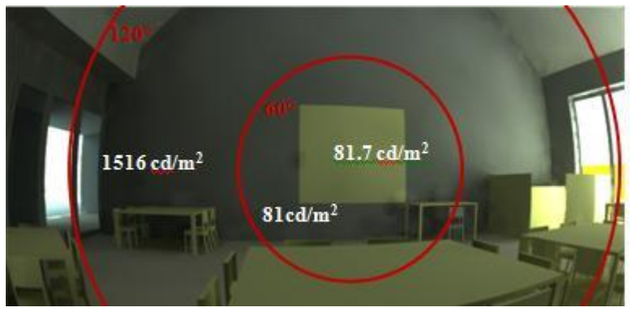
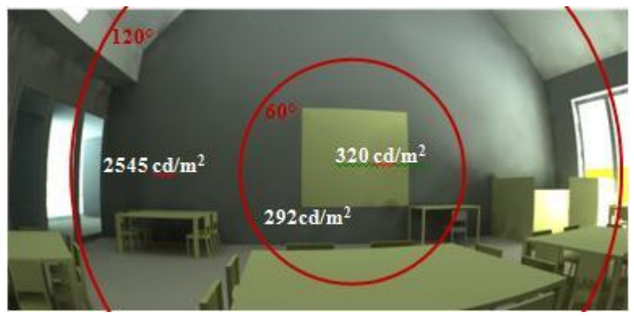
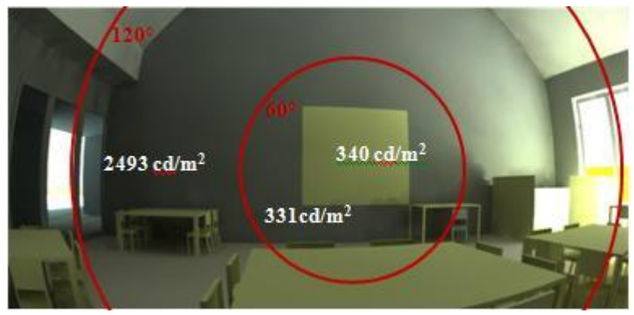
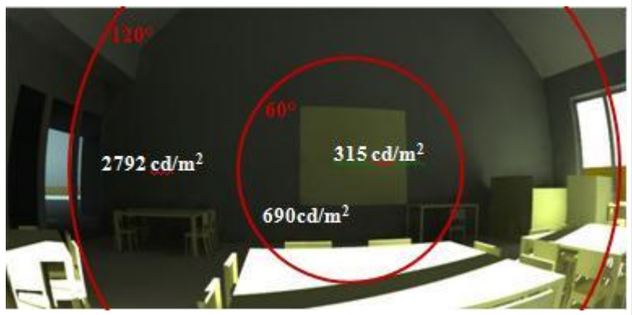
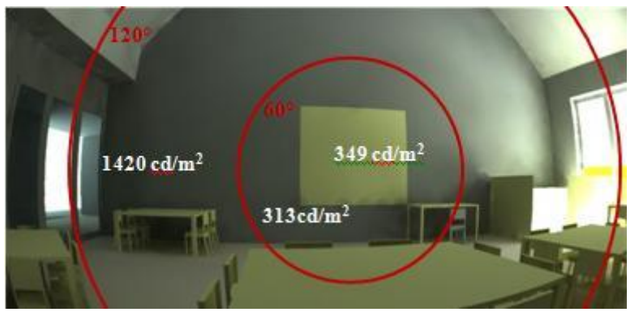
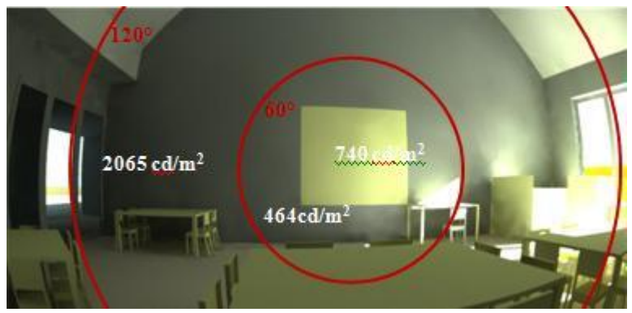
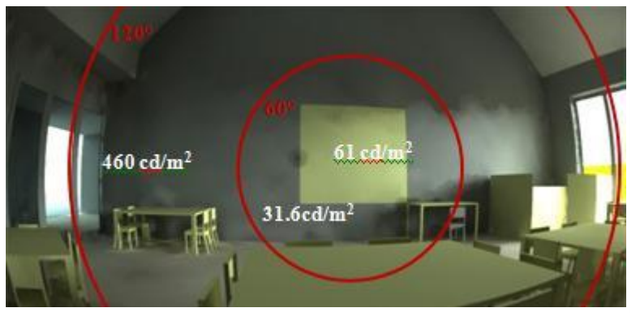
Figure 4.2-10: The visual range set in the model (source: Author).

[1] In this research, only daylight glare is considered rather than glare from artificial lighting.

The Radiance programme computed the luminance levels of the vision task and the surrounding surfaces at the previously-defined moments (i.e. nine representative moments in a year) under sunny sky conditions (i.e. the worst scenario), using the same annual weather data for DA and UDI calculations. Nine interior rendering images were produced by Radiance exhibiting the daylight levels of the classroom in the field of the view of the observer (see Table 4.2-2), and the corresponding false colour luminance maps of the classroom are displayed in Table 4.2-3.

Three readings for each of the luminance of the task, the immediate wall and the far-surround background are marked on each image in Table 4.2-2, representing the average values of the luminance within the relevant range areas rather the values of any specific points. Reading from the table, the average luminance of the whiteboard is approximately between 300 and 400 cd/m^2; it decreases to below 100 cd/m^2 when the solar angle is low during the winter morning or afternoon, but goes above 700 cd/m^2 at the winter solstice (9:00 a.m. and 15:00 p.m.) and at the equinox (15:00 p.m.), respectively.

Table 4.2-2: Fields of vision in the classroom at the summer solstice, the equinox, and the winter solstice at 9:00 a.m., 12:00 p.m. and 15:00 p.m. (Source: Radiance)

	Summer solstice	Equinox	Winter solstice
9:00 a.m.			
12:00 p.m.			
15:00 p.m.			

Note: The task is the white board.

Table 4.2-3: Corresponding false colour maps of internal luminance of the classroom. (Source: Radiance)

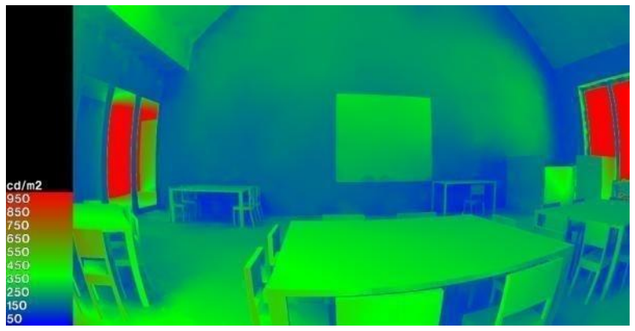
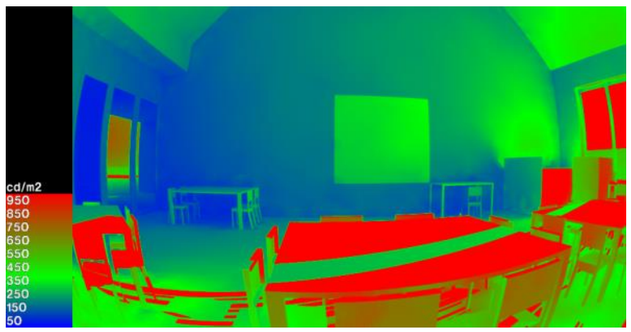
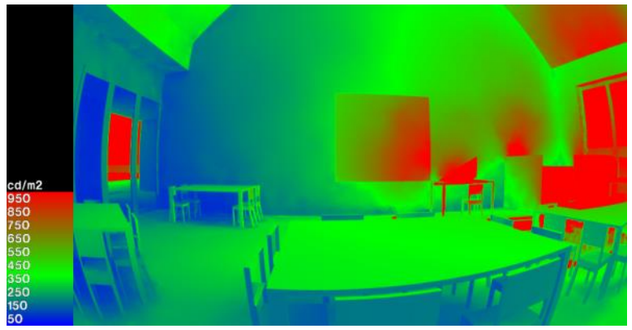
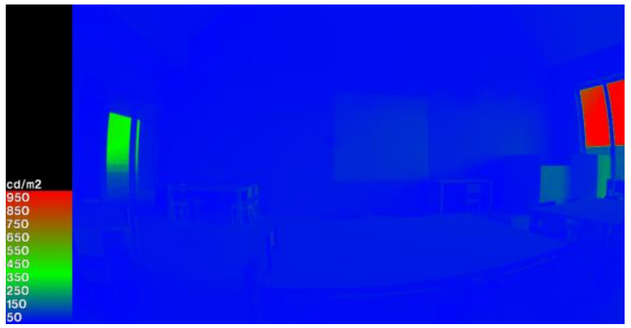
	Summer solstice	Equinox	Winter solstice
9:00 a.m.			
12:00 p.m.			
15:00 p.m.			

Table 4.2-4 shows the ratios of the luminance of the task to the immediate surroundings and to the far-surround background. In general, the luminance levels of the whiteboard are slightly higher than those of the ambient surroundings, which is beneficial to helping observers focus on the task. An exception occurs at noon in the winter solstice due to reflections off the immediate surfaces from direct sunlight. For the ratios of the luminance of the task to the far-surround background, general ratios are within the rule of thumb 1:10, while two ratios exceed the range at the equinox (i.e. 1:12.7) and the winter solstice (i.e. 1:18) at 9:00 a.m. As small areas of the glazing can be seen in the vision field, it can be assumed that the observer who sits in the defined position rarely suffers glare while looking at the whiteboard.

Table 4.2-4: Summary of luminance ratios along the viewing route in the classroom.

Time		Task-to-immediate surroundings	Task-to-far-surround background
Summer solstice	9:00 a.m.	1: 0.9	1: 8.2
	12:00 p.m.	1: 0.9	1: 8
	15:00 p.m.	1: 0.9	1: 4
Equinox	9:00 a.m.	1: 0.9	**1: 12.7**
	12:00 p.m.	1: 0.9	1: 7.3
	15:00 p.m.	1: 0.6	1: 2.9
Winter solstice	9:00 a.m.	1: 1	**1: 18**
	12:00 p.m.	1: 2.2	1: 8.9
	15:00 p.m.	1: 0.5	1: 7.5

According to the false colour luminance maps shown in Table 4.2-3, an obvious contrast of the luminance on the desk surfaces can be found during the winter solstice at 12:00 p.m.. This phenomenon corresponds to the previous finding that low-angle sunlight can enter classrooms and bring the possibility of glare in winter. As internal blinds cannot fully cover the southwest glazing, a

further simulation was conducted to investigate whether the external canopies can prevent low-angle sunlight. Figure 4.2-11 shows the comparison of two luminance maps of the classroom during the winter solstice at 12:00 p.m.; one is without external shading and the other is with external canopies. It can be seen that the issue of high luminance of the desk surfaces is significantly improved by the use of external canopies; however, desired solar radiation for passive solar heating may be simultaneously blocked by the external shading.

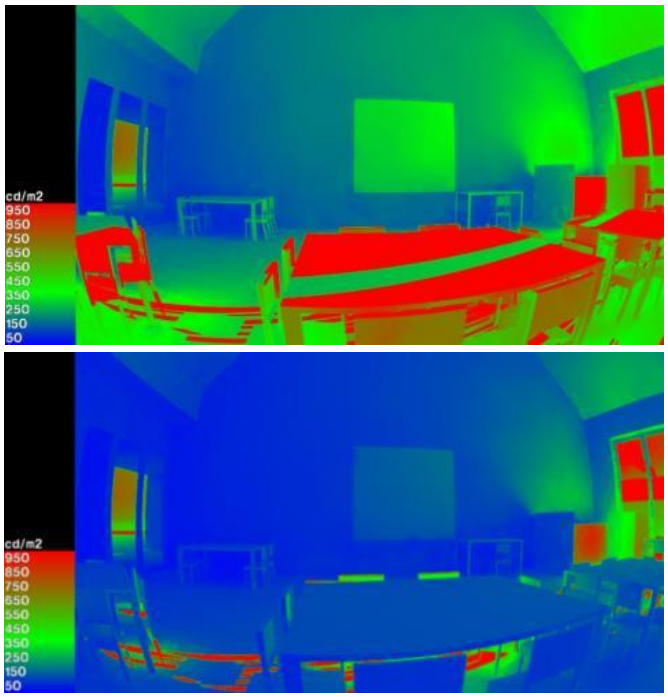


Figure 4.2-11: False colour luminance maps: without external shading (above), with shading (below) (source: Ecotect).

- Summary of daylighting performance

The daylight analysis proves the effectiveness of the design of the fenestration system for classrooms in terms of delivering sufficient daylight. However, the limitations of the glazing design and the shading strategies employed were revealed by the noticeable occurrences of the exceeded UDI and the possibility of glare.

The existing daylighting issues are chiefly due to the design of the primary daylight source, i.e. the southwest glazing. As parts of the southwest glazing were designed as external access points and fire exits, the architects increased the size of the rest of the glazing to maximise daylight in the classrooms and balance the appearance of the southwest façade. This strategy enhances the link between the interior and the exterior both visually and practically, but at the same time it also increases the possibility of 'excessive' daylight and the risk of glare due to low-angle sunlight in winter.

4.2.2 Ventilation and thermal comfort

To analyse the ventilation performance of the school, the same classroom used for daylighting analysis was adopted as the research object to evaluate the efficiency of the ventilation strategies employed. Different modes of natural ventilation in summer, mid seasons and winter were displayed in the following illustrations (see Figure 4.2-12, Figure 4.2-13 and Figure 4.2-14). A further assessment was conducted by using a calculation tool for natural ventilation - Optivent[1] - to investigate whether or not the cooling loads of a classroom in summer can be achieved by cross ventilation.

- Ventilation analysis

In the summer months, prevailing winds from the west are admitted into the building through the openable glazed doors placed on the south-western façade. When the indoor temperature exceeds 26°C (i.e. the upper limit of thermal comfort zone in summer according to the CIBSE Guide A 2006), the northeast-

[1] Optivent is a simple spreadsheet tool for natural ventilation using Macros in Excel, designed by the Department of Architecture and Built Environment, University of Nottingham, UK.

facing rooflight is supposed to be opened automatically by the BMS so that stack ventilation can exhaust warm air out and continue bringing fresh air in (see Figure 4.2-12). When the internal temperature is below 26°C, the occupants also have personal controls to open/close the rooflights via a control panel installed in the classroom in case thermal adjustment is required.

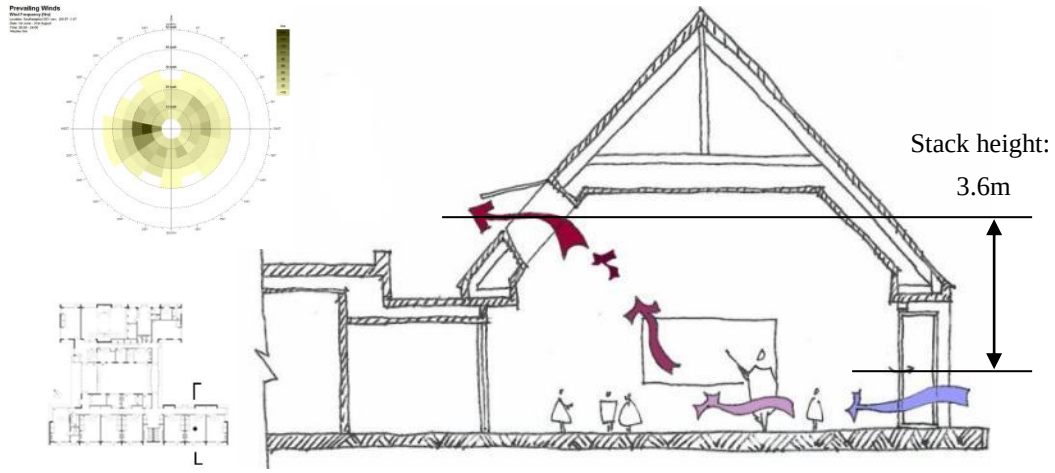


Figure 4.2-12: Diagram of cross ventilation in summer, daytime (source: Author).

In mid seasons (i.e. spring and fall) and mild summer months, prevailing winds from the southwest can be directly admitted into the building. When the south-facing glazed door is open but the rooflight is closed, the wind pressure and temperature difference between the inside and the outside can allow the ventilation air via the bottom of the glazed door, hence prompting single-sided ventilation. Because of the form of the classroom, the large volume under the pitched roof allows the ventilated air to circulate in the space after being heated by the internal gains and then to be exhausted via the high 'outlet' (see Figure 4.2-13). In practice, teachers usually prefer to manually open the doors for air changes during the class break.

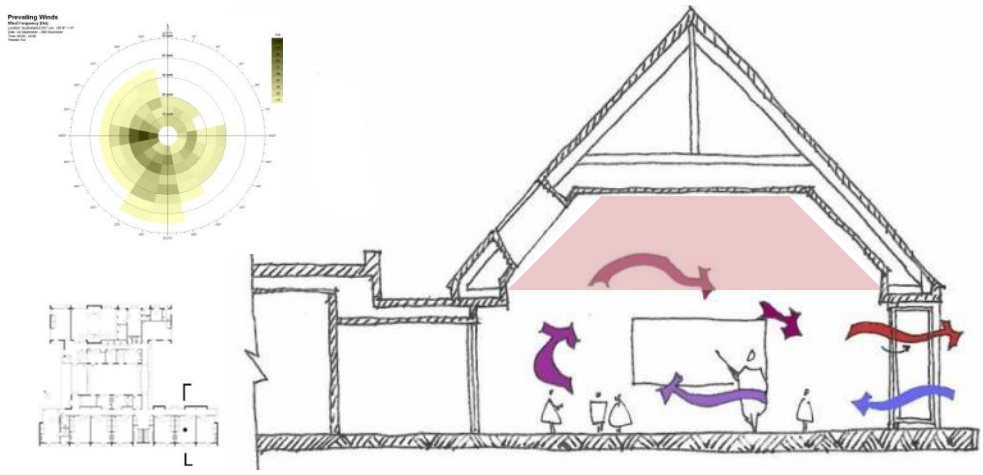


Figure 4.2-13: Diagram for single-sided ventilation in free-running and summer seasons (source: Author).

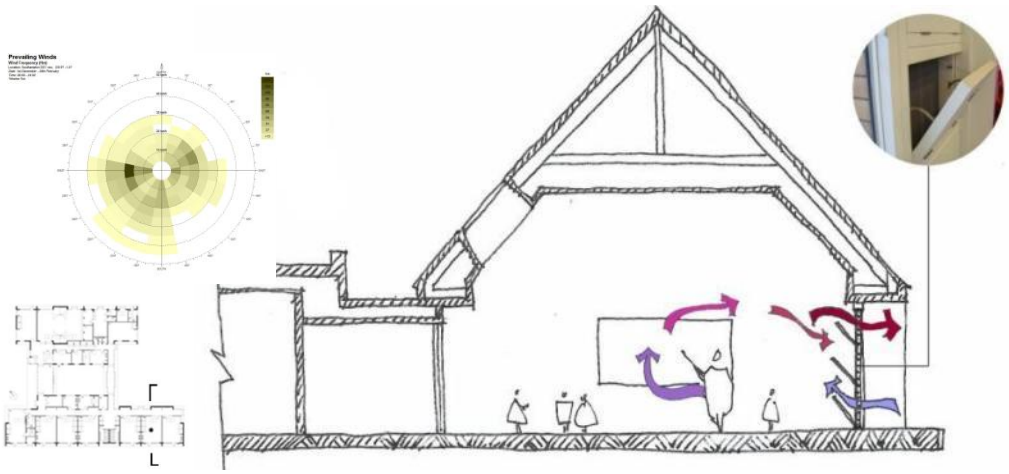


Figure 4.2-14: Diagram for single-sided ventilation in winter (source: Author).

Installations of folding ventilation panels were specifically designed for air changes between the inside and the outside, when neither the glazed doors nor the rooflights are open. Each classroom has three ventilation panels placed on the south-western façade, and each panel was equipped with acoustic attenuation inside to minimise noise from the outside (see Figure 4.2-14). The provision of ventilation panels is intended to provide the minimum required air flow rates in cold seasons or during classes, whilst minimising heat loss and noise from the outside.

To evaluate the quality of ventilated air and the efficiency of the cross ventilation when cooling was required in summer, a simple spreadsheet tool (i.e. Optivent) was used to calculate the achieved ventilation rates, air changes/hour and the cooling loads achieved by the stack vent in the selected classroom driven by heat gains from the occupants and solar gains. The dimensions of the tested classroom, the inlet and the outlet are displayed in Table 4.2-5.

Table 4.2-5: The dimensions of the classroom for ventilation calculation.

Zone dimensions	
Floor area (m^2)	58
Ceiling height (m)	5
Structural area inlet (m^2)	6.48
Structural area outlet (m^2)	2.4
Free open area inlet (%)	90
Free open area outlet (%)	50
Stack height (m)	3.6
Net free area inlet (m^2)	6.5
Net free area outlet (m^2)	1.2

For the calculation, a 'worst case' (i.e. summer solstice at 12 p.m.) was chosen. Based on the location and orientation of the school, heat gains from the solar radiation via the southwest vertical glazing were calculated as 7.47 W/m^2 (refer to Table 4.2-6 for detailed information can). The internal and external temperatures were set at 26°C and 24°C, respectively, and the scenario assumed that 27 children and two teachers occupied in the classroom doing light office work. Based on the values of heat gains from the occupants (i.e. in non-residential buildings) defined in the ASHRAE handbook (2009)[2], the total

[2] An adult's heat gains for office work were defined as 85W in Optivent. Children should be calculated at 75% of the adult male heat gain values.

internal heat gains from the occupants were 30.8 W/m^2. Heat gains from lighting and equipment were not considered in this simulation.

Table 4.2-6: Heat gains of the classroom

Internal heat gains		
lighting	0	Total internal heat gains: 30.8 W/m^2
Occupants (W/m^2)	30.8	
Equipment	0	
Solar heat gains		
Solar radiation-vertical surface (W/m^2)	210[3]	Solar heat gains from the southwest glazing: 7.47 W/m^2
Vertical glazing area (m^2)	7.82	
Horizontal glazing area (m^2)	0	
Transmittance factor-vertical glazing	0.7	
Shading proportion-Vertical glazing (%)	100[4]	
Roof U-values (W/m^{2}K)	0.18	
Total heat gains: 38.2 W/m^2		

Figure 4.2-15 shows the results of four parameters relating to indoor air quality (IAQ) and ventilation efficiency. According to BB 101 (2006), the required air flow rate in teaching areas is 8 l/s per person when the area is occupied, which indicates the capacity of providing fresh air. The test results show that the air flow rate in the classroom achieves 22 l/s per person (i.e. 0.53 m^3/s for 24 adults) when the inlet is fully opened and the outlet is opened by 40%. This value is sufficient to ensure the health of both the staff and pupils in the school; however, it is not sufficient to remove excessive heat gains from the occupants

[3] The solar radiation scores were derived from Table 5.18 in the CIBSE Guide A (2006).

[4] The proportion of shading to the vertical glazing can be seen in Figure 4.2-7 where the southwest glazing can be fully shaded by the overhangs at the summer solstice at noon.

as well as solar radiation in summer. Cross ventilation in the summer via the existing inlets and outlets therefore cannot provide the cooling loads required for the classroom. This finding corresponds to the POE results regarding air temperature in summer; that in some classrooms the occupants suffer overheating problems (refer to Section 4.3.2). The rooflight ventilation opening is therefore too small. This could have been determined at the design stage.

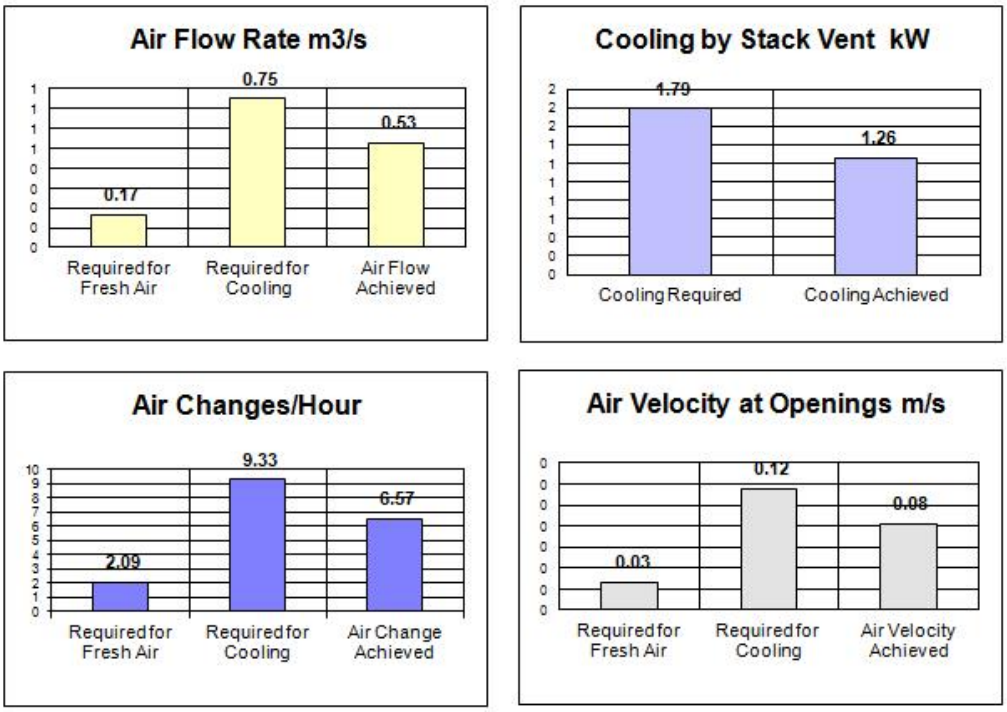


Figure 4.2-15: Ventilation results for the classroom (source: Optivent).

For the other seasons when cooling is not required, the minimum ventilation rate for teaching space, i.e. 3 l/s per person (BB 101, 2006), can be achieved if the inlets (i.e. the glazed doors or the ventilation panels) are open. However, the findings from the on-site observation reveal that, in practice, the ventilation panels installed for air exchange in winter or during classes were not in use. Due to the lack of storage in classrooms, shelves were placed in front of the ventilation panels in most of the classrooms. Some teaching staff also reported

that "*it is very difficult to open these panels*". According to the POE results in terms of the air quality in winter, the issue of "*still air*" was pointed out by most of the school staff (refer to Section 4.3.2). Thus, it is reasonable to conclude that the ventilation strategy employed for natural ventilation in winter, i.e. ventilation panels, does not work properly.



Figure 4.2-16: Internal view of a classroom (source: Author).

Due to the limitations of the equipment that could be used during the study time, another key indicator of ventilation performance, i.e. the internal concentration of carbon dioxide, was not monitored in this investigation. As many previous studies have proved that it is closely related to the productivity of the building users, the assessment of the indoor concentration of CO_2 of the school should be added into the future work.

- Thermal performance

Thermal comfort in the school is a combination of the performance of the heating system, the ventilation provisions, and the glazing and shading design. Based on the POE results regarding the indoor temperature of the school, the issue of uneven temperature in different spaces was revealed. Hence, to

investigate whether thermal comfort is fully achieved in the school, three spaces in different locations of the school were selected as monitoring targets; a representative classroom in the southern block, a reception classroom in the western corner, and an office space in the northern block (see Figure 4.2-17).



Figure 4.2-17: The locations of Tinytag data loggers in the specified spaces (source: HCC Property Service).

The following thermal comfort parameters were measured during the occupied periods at the specified internal spaces as well as the parameters of the external environment simultaneously: (a) dry bulb temperature (T) and (b) relative humidity (RH), measured via Tinytag data loggers. Measurements were carried out with the sensors at a height of 1.1 metres near the glazed areas in each space specified. Measurements made every second were averaged over three-minute intervals. Based on the school timetable the school, data had been recorded on-site for three weeks in free-running seasons (i.e. September-October 2012[5]) and for one week[6] in heating seasons (i.e. February 2012). In addition, the common schedule of window opening was recorded based on the

[5] June, July and August are the school summer holidays.

[6] Three-week on-site monitoring was also conducted in heating seasons. However, the first two weeks of the on-site monitoring period were the half-term break when the school was not occupied, so only the data for the last week was displayed in this study.

staff feedback. For classrooms, glazed doors on the external façade are often open during lunch break (i.e. between 12 a.m. and 1 p.m.), and the rooflights in classrooms will be automatically open if the indoor temperature exceeds 26 °C. For the office, the user (i.e. the head teacher) controls the opening of the window.

With regard to the indoor temperatures for teaching and office spaces in schools recommended by CIBSE Guide A (2006), the suggested temperature in the heating season is between 19°C and 21°C, and the temperature in summer and the free-running season should not exceed 26°C. The relative room humidity should be above 40%.

- Thermal performance in the mild seasons

Table 4.2-7 shows the summary of the thermal comfort results of the specified spaces for a three-week period in the mild season, i.e. between 17 September 2012 and 15 October 2012. In this period, the temperatures found in the school vary with the warmest between 21.9°C (i.e. the end classroom) and 27.4°C (i.e. the office) and the coolest between 16°C (i.e. the end classroom) and 18.2°C (i.e. the mid classroom), depending on the room locations, configurations and glazing design. The average RH of the monitored spaces is generally above 40%.

The highest indoor temperature reached during the monitoring period is 27.4°C in the office, indicating that the user who occupies the office (i.e. the head teacher) could suffer some discomfort in summer or during the free-running season due to high temperatures inside of the room.

Table 4.2-7: Summary of the on-site measurement results for a three-week period in the mild seasons.

Room	T_{min} [°C]	T_{max} [°C]	T_{ave} [°C]	RH_{min} [%]	RH_{max} [%]	RH_{ave} [%]
Middle classroom	18.2	23.4	20.8	37.8	72	54.9
Reception (End) classroom	16	21.9	18.9	37.0	71.6	54.3
Office	17.9	**27.4**	22.7	26.6	60.8	41.7

Reading from the line graph (Figure 4.2-18) that displays a continuous three-week plot of temperatures recorded in all monitored spaces and the outside environment, the temperature of the office is generally higher than the temperature of the other two classrooms, and goes above 26°C on four occasions during the monitoring period. This is chiefly due to the glazing design and the opening allowance in the office. The glazing for daylighting in the office orients towards the southwest, and takes up over one-third of the external wall without the provision of external shading. The opening for ventilation is quite narrow, and cannot be fully opened (see Figure 4.2-19). Thus, it is reasonable to assume that the ventilation rate required may not be achieved in the office leading to the potential overheating problem. Additionally, based on the solar analysis of the school at the autumn equinox at 12 o'clock, noon (see Figure 4.2-20), direct sunlight can easily enter the office without obstruction. Although the internal blind can be pulled down to prevent glare or excessive daylight from direct sunlight, heat gains from solar radiation can still impact on the thermal comfort of the users in the office. This corresponds to the feedback of the head teacher regarding the thermal environment of his office that the issue of overheating exists (refer to POE results in Section 4.3.2).

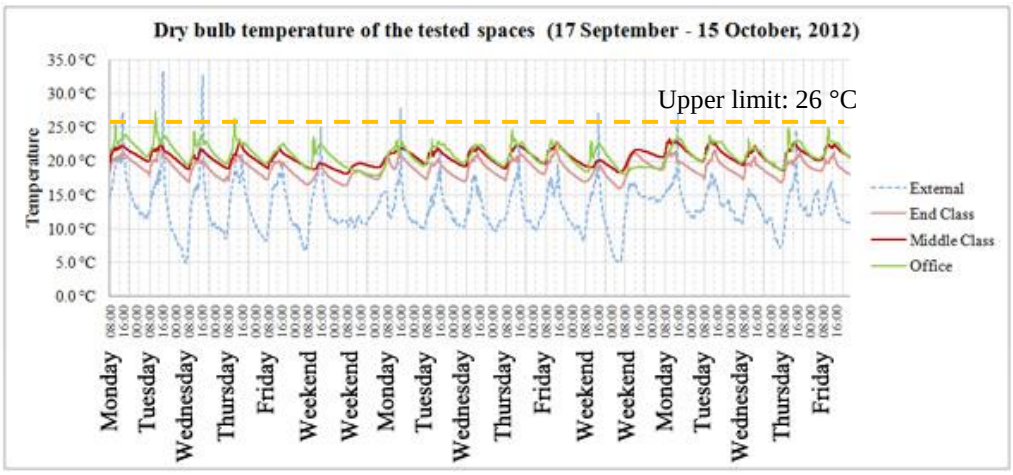


Figure 4.2-18: Temperature recorded in the monitored spaces over three weeks in the free-running season (source: Author).



Figure 4.2-19: Glazing design and the openings in the office (left) and the reception classroom (right) (source: Author).

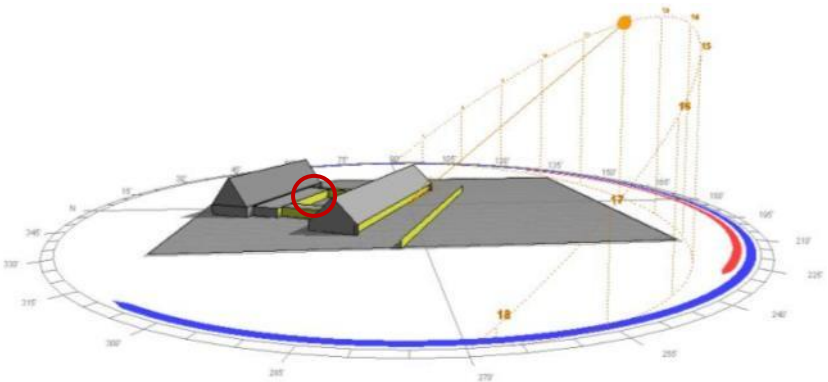


Figure 4.2-20: The solar analysis at the Equinox at 12 a.m. (source: Ecotect)

On the other hand, the line graph (Figure 4.2-18) also illustrates that the indoor temperature of the reception classroom seems to be generally lower than the simultaneous temperature of the middle classroom, where warmth appears to be caused by the smaller size of the middle classroom and less glazing exposure. Considering of the depth of the reception classroom (i.e. 10.7 metres), the architect placed wide glazed areas on the external walls of the room facing the northwest and the northeast, composing of a glazed corner in the reception classroom (see Figure 4.2-19). This design strategy is intended to improve daylighting performance of the reception classroom by introducing more daylight from the north, but at the same time it enlarges the area of the surfaces that have higher heat conductivity and which receive very little solar radiation. Thus, it is comparatively easier for the reception classroom to lose heat gains via the 'glazed corner' compared with the middle classroom. This finding explains why some staff pointed out the existence of "*uneven temperatures*" among different rooms in the POE results.

- Thermal performance in heating seasons

Heating is normally provided in the school when the external temperature is below 16°C. For the thermal performance of the school in the heating season, Table 4.2-8 shows the summary of the on-site measurement of the selected spaces between 18 February and 24 February 2012. In this period of one week including a weekend, the temperatures found in the school vary with the warmest between 21.6°C (i.e. the end classroom) and 26.2°C (i.e. the office) and the coolest between 9.2°C (i.e. the end classroom) and 11.2°C (i.e. the middle classroom). In terms of the average RH, it is generally above 40%.

Table 4.2-8: Summary of the on-site measurement for a one-week period in the heating seasons.

Room	T_{min} [°C]	T_{max} [°C]	T_{ave} [°C]	RH_{min} [%]	RH_{max} [%]	RH_{ave} [%]
Middle classroom	10.7	24.7	17.7	37.3	65.2	51.3
Reception (End) classroom	9.2	21.6	15.4	37.8	74.1	56
Office	11.2	26.2	18.7	28.2	59.5	43.9

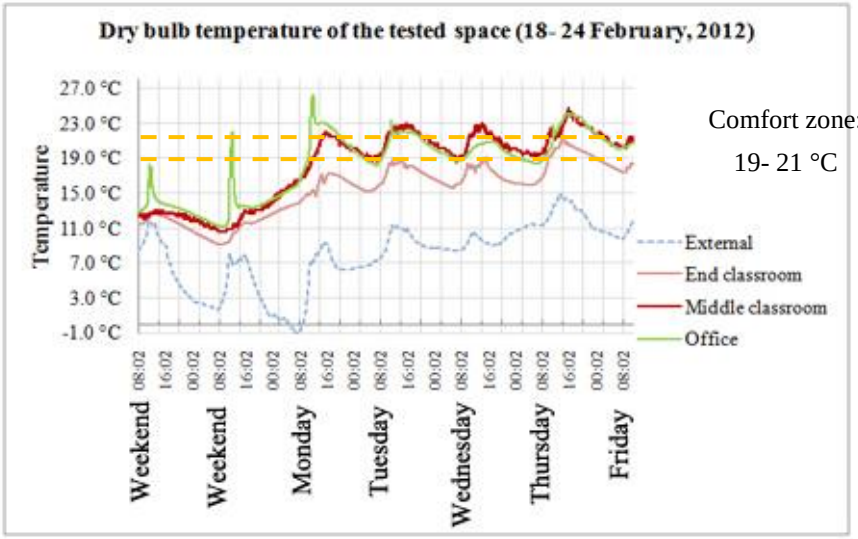


Figure 4.2-21: Temperature recorded in the monitored spaces over one week in the heating seasons (source: Author).

According to Figure 4.2-21 that displays a continuous one-week plot of temperatures recorded in the monitored rooms and the outside environment, it can be seen that temperatures below 15°C occur mostly during the weekend. For the working days, temperatures of the monitored spaces are generally between 15°C and 23°C, indicating a relatively large temperature difference between the daytime and the night-time.

Reading from the graph, temperatures of the office and the middle classroom on the working days are relatively similar and within the suggested thermal

comfort zone (i.e. between 19°C and 21°C). This implies that thermal comfort is broadly achieved in the office as well as the middle classroom in most occupied hours. Nevertheless, the highest temperature of the office was recorded at 26.2°C, indicating that heating could be excessively provided so that the issues of the 'winter-overheating' and less energy efficiency appear to be present.

For the temperature of the reception classroom, it is normally 4°C lower than the simultaneous temperature of the middle classroom. Over the monitored period, the highest temperature of the reception classroom is generally below the bottom limit of the comfort zone (i.e. 19°C) with an exception during the Thursday afternoon. This phenomenon indicates that there could be some discomfort among pupils and the staff occupying the reception classroom due to the thermal environment. In accordance with the previous finding with regard to the uneven temperatures of different classrooms, the only cause of thermal discomfort in the reception classroom in the heating season is the combination of the dimensions of the room and the glazing design, particularly the large glazing facing the northeast and the northwest.

- Efficiency of the heating system

In the heating season, heating in the school is provided via the under-floor heating system and controlled by the BMS. Hot water for heating is provided by five ground-source heat pumps powered by electricity. According to the schedule set out in the BMS, the heating system starts to work at 4:00 a.m. and stops providing heating after 13:00 p.m.

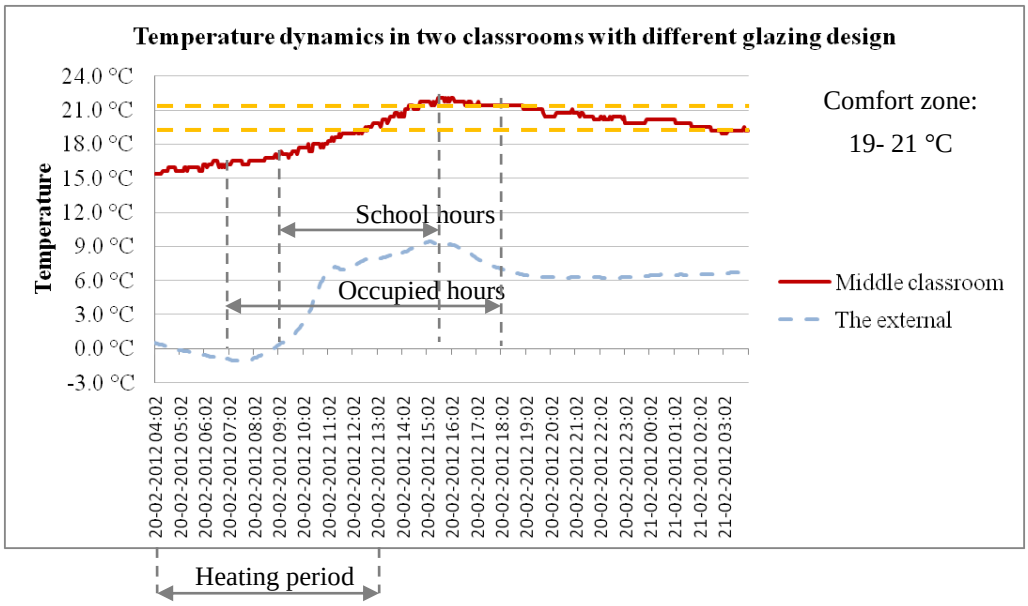


Figure 4.2-22: Temperature dynamics in the middle classroom (source: Author).

Figure 4.2-22 illustrates the temperature dynamics in the middle classroom on the Monday of the monitored week (i.e. 20 February 2012). After a weekend over which heating was not provided, the initial temperature of the middle classroom was 15°C before the provision of heating. Over the period of five hours between 4:00 a.m. (i.e. the starting time of heating) and 9:00 a.m. (i.e. the start of classes), the increase of the indoor temperature was approximately 3°C only. Due to the increase of internal heat gains from the occupants from 9 a.m., the indoor temperature of the middle classroom reached the lowest limit of the comfort zone until the lunch break at 12:00 p.m. The indoor temperature tended to increase from 19°C at noon to 22°C by the end of the school day (i.e. 15:30 p.m.), even though heating ceased after 13:00 p.m. After pupils left the school, the indoor temperature started to reduce, but it still stayed above 18°C until the next time the heating started again, on Tuesday morning (i.e. 21 February 2012).

Based on the above analysis, it infers that the under-floor heating system in the school has a slow response to changes in conditions. If heating was not

provided during the weekends or holidays, it could take nearly eight hours for the indoor temperature to achieve the comfort zone, indicating there could be some discomfort among the users in the morning period due to the thermal environment. Referring back to the POE results regarding the control over heating, the issue of no immediate personal means to adjust the heating system was pointed out by the school staff. Unless windows or doors are opened, the thermal environment of the school in the heating season can only be adjusted by the users to a very limited extent, possibly resulting in satisfaction and decreased productivity (Brager and de Dear, 1998; de Dear and Brager, 2002).

On the other hand, after the internal heat gains from the occupants were no longer provided (i.e. after 16:00 p.m.), the slow speed of the decline on the indoor temperature proves the insulation performance of the building fabric, particularly the external walls and the roof.

- Summary of ventilation efficiency and thermal comfort

The ventilation and thermal analysis reveals the advantages and disadvantages of the design strategies employed in the school for natural ventilation and thermal comfort. Generally, the ventilation provisions for classrooms, i.e. the southwest glazed doors and the northeast rooflights, can offer minimum ventilation rate required for fresh air, but some difficulties may be encountered when excessive heat gains from the occupants and solar radiation need to be removed when cooling is required. The ventilation panels designed for air exchange in the heating season are not in use due to their practical applicability. Hence, ventilation in the heating season can only be achieved via opening doors in classrooms, which can lead to less thermal comfort and undesired heat loss.

For the factor of thermal comfort, the performance of the building fabric is good in maintaining the indoor temperature at a comfortable level. Nevertheless, the issue of the overheating problem in the office and the existence of uneven temperatures across the same functional spaces (i.e. classrooms) are revealed via the analysis. The key reason of the above thermal issues is the combination of varied glazing designs and opening allowances in different spaces. For instance, the reception classroom, which has a larger floor area and more glazing exposure in comparison with a typical classroom, always has lower indoor temperatures compared with the simultaneous temperature of the typical classroom. The large glazing exposure to the north was designed to improve daylighting performance of the reception classroom depending on its depth; however, it decreases the thermal comfort of the room in cold months at the same time. Sufficient glazing design is important in schools for daylighting and passive solar heating, but it requires a comprehensive understanding regarding the effects of the glazing design on the aspect of daylighting performance and thermal comfort.

The results of the on-site monitoring in the heating season have revealed an issue regarding the reaction speed of the under-floor heating system that it needs a comparatively longer period to increase the indoor temperature in comparison with the traditional radiators. In addition, due to the use of the under-floor heating system, personal control over heating has obviously been reduced. Consequently, adaptive thermal comfort depending on the occupant's control over the thermal environment may be decreased as well.

4.2.3 Energy and carbon performance

An assessment regarding the energy efficiency of the school was conducted by Hampshire County Council in July 2010, two years since the building became occupied. Based on the assessment results, the school achieved *Rating D* (i.e. the score of 87) in the DEC[1], indicating that the energy performance of the school is slightly better than typical primary schools in the UK, but this is a long way from the Government's target for 'zero carbon' schools. Detailed information of the DEC of the school are set out in the Appendix.

Based on the energy consumption report provided by the head teacher, the annual energy use of the school in terms of gas and electricity between 2009 and 2011 is displayed in Figure 4.2-23, compared with two benchmarks for primary schools in the UK, i.e. the benchmarks set out in the DEC for typical primary schools in the UK (2010) and the benchmarks provided by the Department for Education (DfE) for the top 10% schools[2] in the UK (2004). Based on these benchmarks, we can see that energy demand in terms of heating (gas) for school buildings is generally larger than the electrical demand.

[1] Ratings A to G represent energy efficiency of the building from high to low, e.g. the score of typical schools in the UK is 100 which matches Rating D (score 76- 100).

[2] Based on the DfE's *Energy and Water Benchmarks for Maintained Schools in England 2002-2003*, the schools in the top 10% represent those that used the least energy consumption across all UK schools.

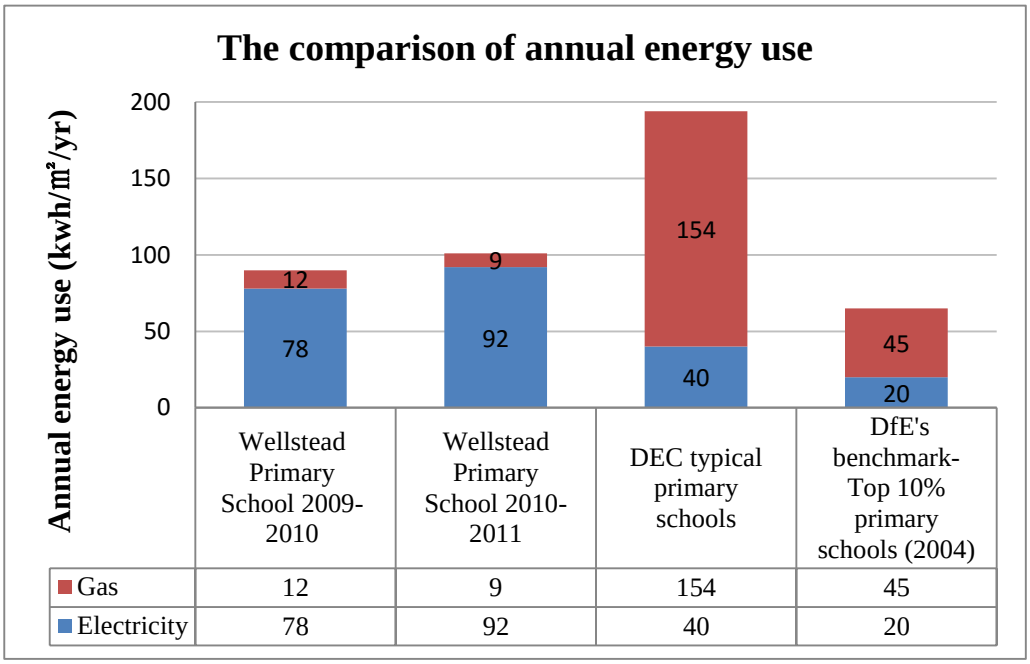


Figure 4.2-23: The comparison of annual energy use between Wellstead Primary School and benchmarks (source: Author).

Reading from Figure 4.2-23, it is noteworthy that the energy use of electricity consumption of the studied school is much higher than its energy use of gas consumption, which appears to be largely caused by the heating source of the school, i.e. five ground-source heat pumps powered by electricity. Comparing the school's energy use of gas with the benchmarks indicates a very good performance in that it only consumed fossil fuels around 10kwh/m^2/yr. However, the electrical demand of the school is nearly twice and four times more than the energy use of electricity consumption of typical primary schools and the top 10% of schools in the UK, respectively.

For the total energy consumption, the annual energy performance of the Wellstead Primary School is around 100 kwh/m^2/yr, which is about half of the total energy use for typical primary schools in the UK but approximately 30

kwh/m^2/yr more than the top 10% schools which performed energy-efficiently. Furthermore, it compared the annual carbon emissions of the school (i.e. 2010/11) with the DfE's benchmark for the top 10% schools in the UK (2004), and the results are illustrated in Figure 4.2-24.

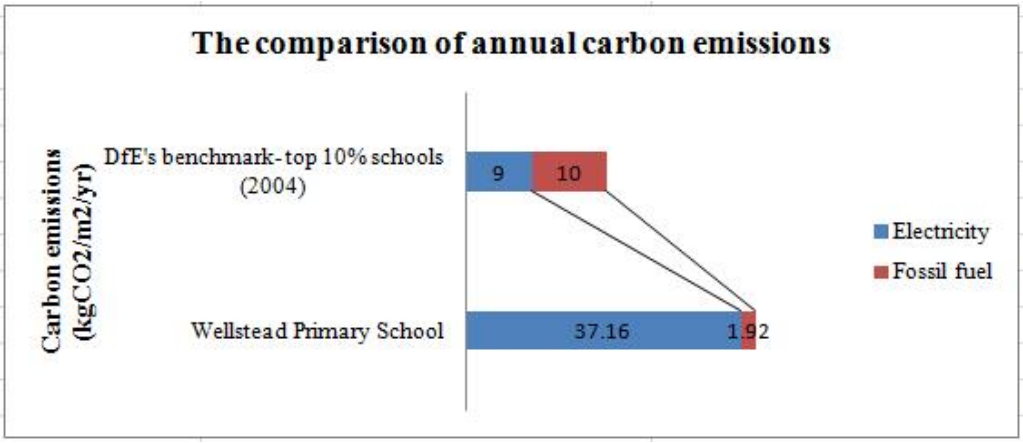


Figure 4.2-24: The comparison of annual carbon emissions between the school and the DfE's benchmark (source: Author).

For the Wellstead Primary School, the annual carbon emissions from the energy use of electricity consumption and fossil fuels (i.e. gas) were 37.16 and 1.9 $kgCO_2/m^2/yr$, respectively. In comparison with the top 10% schools, the carbon emissions from the electricity consumption of the school is around four times higher than the DfE's benchmark, while the carbon emissions from fossil fuels used by the school are five times lower than the benchmark due to the use of gas only for water, heating and cooling.

- Summary of energy performance

Although the school was designed to perform sustainably, the above analysis with regard to the energy and carbon performance of the school implies a gap between the design intent and the actual energy performance. Environmental

technologies, such as ground-source heat pumps, were employed to minimise carbon emissions, while the high energy demand of electricity consumption could be due largely to the ground-source heat pumps, making the school less 'sustainable'. Additionally, the high electricity use could be resulted in the frequent use of electrical equipment, such as laptops, service equipment and artificial lighting. Further energy performance assessment, such as the TM22, is required to investigate that the high electricity use in terms of more than double that of typical was because of plug loads, smart boards or heating.

4.3 POE results: occupant feedback

To understand the actual building performance from various points of view, two different surveys were conducted in February 2012 with the head teacher and the school staff, respectively. The survey carried out with the head teacher consisted of a questionnaire and an interview. The questionnaire, derived from the *10 criteria for successful school design*[1] (CABE, 2011), was to investigate the headteacher's level of satisfaction with the overall design quality, particularly with regard to the impact of the design strategies described in Section 4.3.1. The interview was conducted on the author's second visit (24 February 2012), and detailed questions were drawn up based on the staff's feedback regarding the school in use, which looked for the potential reasons why some environmental issues were raised by the school staff.

Another survey run with the school staff used the BUS Occupant questionnaire that evaluates satisfaction and comfort level of the occupants regarding the building design and actual building performance via a number of variables.

[1] CABE published 10 criteria for successful schools in 2011, which included 10 aspects related to design quality of schools in the UK. Details can be referred to in Chapter 2.

Twenty five school staff members[2] were involved in this study.

4.3.1 Overall design quality

According to the survey results, head teacher Wharton was satisfied with the overall design quality of the school, particularly the relationship established between the school and the community. He expressed that the school ethos and identity has been enhanced by the "*visual link*" and the "*real connection*" set up between the school and its surrounding environment, such as its appealing appearance and convenient accessibility. Additionally, the after-hours use of facilities such as the music room and the hall is very welcomed by the community. "*This harmonious relationship has strengthened the image of local education*" (Richard Wharton, interview, 24 February 2012).

In spite of the external appearance, the internal environment was also commended by the head teacher as a "*happy and special environment*" for both students and the school staff. Wharton highlighted the advantage of separating the teaching spaces from the communal activity spaces as it supplies "*a desired learning environment with unnecessary interruption*", and he also indicated that the circulation design has provided a clear and easy-to-follow route for pupils and visitors.

> *"We feel immensely proud and privileged to be using the building. It wows people when they look around the school and creates a positive first impression that the staff then work hard to build upon"* (ibid).

[2] In 2012, there was a total of 25 staff in Wellstead Primary School.

Although most design aspects have fulfilled the head teacher's expectations, a few issues relevant to the building's operational system and the efficiency of the environmental technologies employed were pointed out by Wharton, such as the use of BMS and the efficiency of ground-source heat pumps. Detailed feedback on these issues is set out in the following section.

4.3.2 Successful factors and existing issues

The BUS occupant survey was carried out on the first visit to the school in February 2012, a year and a half after occupation. As the instruction of the BUS Occupant questionnaire claims that "*school pupils whose ages are under 11 are too young to provide reliable answers*" (BUS, Instruction for Project 1212, 2012), only the school staff were involved in the study. The final response rate achieved was 76%.

Figure 4.3-1 shows a summary of the occupant feedback on the chief variables in terms of architectural design and the quality of the indoor environment. As the scores of the major variables listed below are better than those on the current BUS dataset[3], 'comfort' and 'satisfaction' seems to have been achieved in Wellstead School in the main. Staff said that "*the school is a great environment to work in… The space of the school is high, bright and tidy which makes you feel happier*" (BUS occupant survey, 2012). It is noteworthy that the summary results can be different from detailed results for different elements.

[3] As the number of buildings studied grows every year, the current BUS Methodology uses the "*most recent 50 qualifying buildings*" for the benchmarking. In this case, the benchmark used for Wellstead is the most recent 50 qualifying non-domestic buildings in the UK.

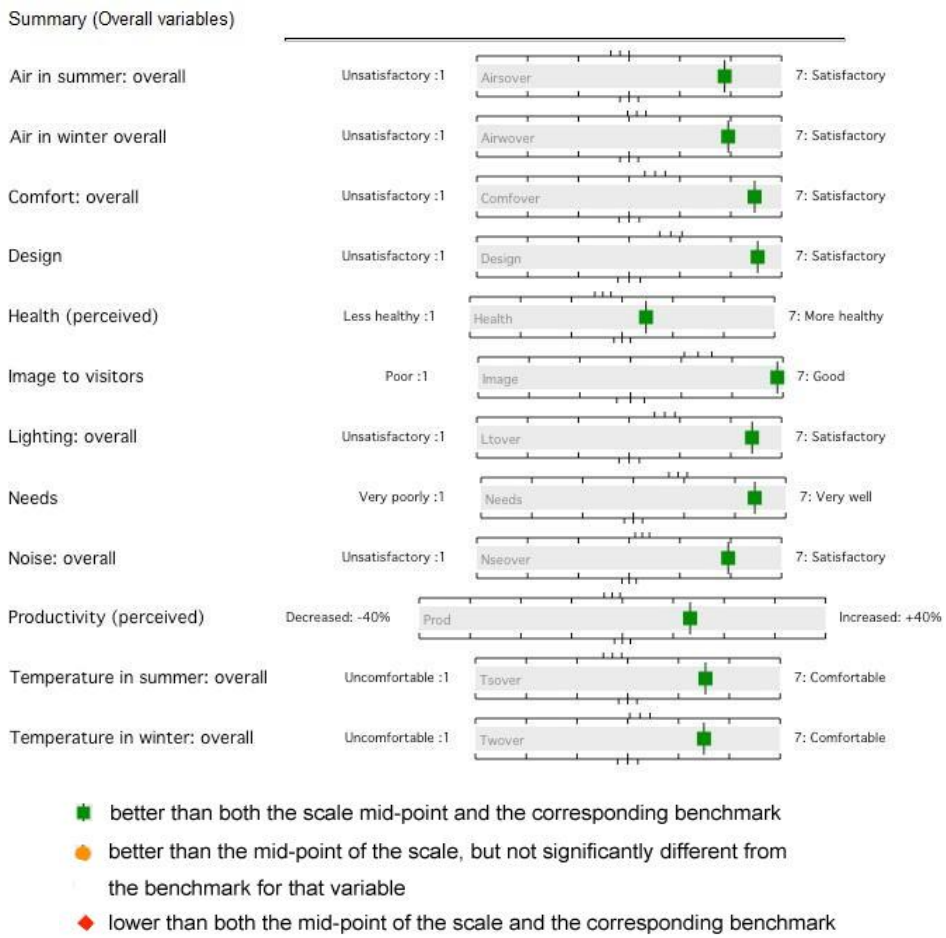


Figure 4.3-1: Wellstead's POE summary of overall variables (source: Building Use Studies).

Although the POE summary demonstrates a high level of satisfaction among the occupants with the overall building design, some specific issues relevant to the building's indoor environment as well as the building's operational system in use were revealed through the assessment of a series of precise variables.

In this study, variables which receive much higher scores than the BUS dataset were defined as *'successful' factors*, and variables whose scores are worse than either the benchmark or the scale mid-point were considered as *existing issues*. According to the detailed feedback from the school staff, several successful factors and existing issues were summarised as below. Detailed POE results can be referred to in the Appendix 5.

- **Successful factors**
- External appearance and the interior colour scheme

The occupants gave very high scores on the variables of 'Design' and 'Image to visitors'. They commented that the school has provided an "*attractive and healthy*" environment to both its users and visitors. The interior of the school was also considered to successfully "*promote calm in children and adults*" (Staff, BUS survey, 11 February 2012).

- Spacious circulation

The sufficiency of the corridor space was highlighted by the majority of the staff. Some staff considered that the internal circulation design has created spaces for "*easy movement*" and has also provided opportunities to "*stimulate social activities*".

- Considerate design for special needs students

In terms of the variable of 'Needs', 94% of the staff believe that the school design has fulfilled their demands and expectations very well. The design of the Special Educational Needs (SEN) room was specifically praised by the teaching staff.

"*The design of the SEN room retains the personal environment but also allows appropriate visual communication between the inside and the outside via the glazed door" (ibid).*

- Limited noise

Occupants gave very high scores for the variables related to 'noise'. Because of the layout of the school, only approximately 10% of the staff report that they have been affected by some noise from colleagues at times.

- **Existing issues**
- Insufficient spaces for group work and extra-curricular activities

As the school provides extra-curricular activities for pupils, e.g. cookery, technology and art, the spaces designed for these activities were described as "*not adequate enough to support the activities*". Some staff further commented that "*chairs in the cookery room splinter the group work spaces*".

- Not enough working desks for the staff

The availability of working areas, e.g. small working desks, was raised by some staff as a design issue that hindered working productivity. For primary schools, teaching staff usually work in classrooms where only small working desks are located; therefore it seems that a proper working area for teachers in classrooms is needed.

- Excessive natural light and glare from the sun and sky

The staff described the school as "*a bright environment that has promoted the well-being of children and adults*". The majority of them gave comparatively high scores on the lighting variables, including daylighting and artificial lighting.

A few issues particularly relevant to daylighting were however specified by

some staff; 32% of the staff pointed out that the classrooms can be "*too bright*" at times, particularly in sunny conditions while the blinds are in operation, and 80% of the staff admitted that the occurrence of glare from direct sunlight when the solar angle is low, normally in winter months.

> *"When the sun is low, our blinds have a large gap where the door is, the so sunshine interrupts learning… and there are no blinds on the fire exit doors in classrooms, so the sun shines through… We put up large sheets of paper to block it out"* (Staff, survey, 11 February 2012).

Although daylighting strategies, e.g. overhanging eaves and blinds, were employed by the architects to prevent potential daylighting issues, the concerns regarding excessive natural light and the glare risk in winter months indicate the gaps between design intent and actual building performance. Further analysis in terms of the factual daylighting performance can be found in Section 4.2.1.

- Insufficient air movement in winter

With regard to air quality, a few variables such as air movement, relative humidity and air variation were included in the BUS survey. Most staff believed that the ventilation system works better in summer than it does in winter. The issues of slightly dry air in summer and insufficient air movement in the winter months were raised by nearly half of the staff.

One reason leading to the differentiation of ventilation performance between summer and winter is the occupants' habits and behaviour. The head teacher explained that "*the occupants do not prefer to open doors or*

windows in heating seasons because of the cold" (Wharton, interview, 24 February 2012). In winter months, doors or windows are rarely opened during class breaks, and air exchange can only be accomplished when the rooms are empty, e.g. in lunch breaks. Another possible reason for insufficient air movement in winter is because of the inefficiency of the ventilation panels, which were particularly designed for the provision of air exchange in cold seasons based on the interview with the architect. The occupants are permitted control over ventilation manually, via operating doors, windows and ventilation panels. However, a teacher who usually works in the classrooms asserted that "*these panels are too tight to open*". Additionally, it can be observed on-site that some internal storage shelves were placed in front of the panels, which have blocked the use of these installations.

- Overheating issue in summer

In terms of the thermal aspect, the score for the overall indoor temperature (in summer and winter) is comparatively higher than the benchmark. Only 7% of the staff considered the temperature in summer as "*too hot*". However, the head teacher pointed out a few thermal issues, i.e. variable temperature in different spaces and overheating problem in classrooms in summer. "*Some rooms get warmer or cooler than others*", reported Wharton.

It is interesting to note the conflict between the head teacher's feedback and the staff's views on thermal comfort. One cause of the potential overheating problem can be the excessive solar radiation or inadequate air exchange in summer months. In addition, behaviour of the occupants and their thermal

adaptability may also affect thermal sensations. Further analysis regarding the actual thermal performance is shown in Section 4.2.2.

- Difficult personal control over heating

To minimise the waste of energy use, the building is automatically controlled by the BMS but allows manual operation over certain environmental aspects. In terms of the variable of 'control', the occupants were generally satisfied that they could adjust the lighting in the classrooms via modifying lighting sensors and control ventilation by operating windows and doors. Nevertheless, 84% of the staff identified the issue of lacking control over heating.

In heating seasons, the building is heated via the under-floor heating system, and the temperature of different zones is adjusted by the BMS based on the present indoor temperature. For example, if a classroom's temperature exceeds 26°C, the rooflight in this room will be automatically opened by the BMS to release the excessive heat gain; the occupants do not have controls to adjust the heating system unless they are operating the window openings. As per the head teacher's feedback, the under-floor heating system takes a very long time to react (Richard Wharton, interview, 24 February 2012). Thus, immediate alterations cannot be made in a short period of time, which may lead to user discomfort at times. Additionally, the unpredictability of the system appears 'unwelcome' to the school users. "*It is a bit annoying when the rooflight opens suddenly with a sound in class… It can interrupt learning easily*" (Staff, survey, 11 February 2012).

- Inefficiency of the operational system

In spite of the issue of personal controls, the head teacher critically assessed how smoothly and conveniently the building can be operated and maintained. In terms of the use of BMS, neither the architects nor the engineers have taught the relevant staff how to operate the system as it should be, and the location of the BMS is at the loft space of the northern block, which makes it very difficult to reach when there are settings of the system required adjustment. The following citation of the head teacher proves the importance of understanding how to operate the building.

> *"In order to supply a comfortable environment for the school staff and students, the heating needs to be started at 4 a.m. in the morning, and should be turned off at lunch time to avoid overuse of energy. It took us over a year to work out the most appropriate schedule, and we paid an extremely high energy bill as a result of the inappropriate operation in the first year of occupation"* (Wharton, interview, 24 February 2012).

Regarding the sustainable technologies employed, i.e. the ground-source heat pumps, Wharton also questioned whether it is necessary to utilise this type of technology for school buildings, even though it can reduce carbon emissions. He said, "*The remarkably high amount of electricity demanded to support the five ground-source heat pumps, i.e. 78kwh/m^2/yr, led to a very expensive energy bill in the first running year*" (ibid.).

4.3.3 Summary of POE results

Compared with the BUS benchmark, the survey results regarding the overall design quality of the school are mostly positive, indicating the success of some design strategies, e.g. the spatial arrangement, the appearance of the school and

interior design. Nevertheless, some issues in terms of too much natural light in classrooms, glare risk, thermal discomfort in the office and the lack of personal control over heating were revealed by the occupants.

4.4 Summary

To uphold the follow highly reputable traditions of Hampshire school design, the Wellstead Primary School was designed by the HCC Architect to provide a learning environment that is both comfortable for the occupants and performs energy-efficiently. Working with the in-house engineers and the external consultants, some ‘successful’ design strategies as well as a host of passive environmental strategies learnt from the precedents of Hampshire schools were employed by the design team. To achieve a sustainable target, several renewable technologies, such as ground-source heat pumps and photovoltaic panels, were used as environmental ‘bonus’ to minimise carbon emissions of the school. The RIBA Awards (2009) rewarded the design of the school based on its design quality as well as environmental considerations.

To investigate whether or not this award-winning school has performed environmentally and achieved the design expectations, an evaluation of the actual building performance of the school was conducted. Successful factors and existing issues regarding the design quality and factual building performance were revealed from the POE and BPE results (Detailed results can be referred to in previous sections). Overall, comparatively high satisfaction index and comfort index regarding the school design and the indoor environment has been attained in the school, compared with the latest BUS benchmark (2011) at the time of this study (refer to Figure 4.4-1 and Figure 4.4-2). The high value of these two indices indicates that the school design has

suited the demands of the occupants and achieved the expectations of the occupants to a large degree; however, to some extent, the high value of these indices could result from the occupants' high tolerance of the design faults, particularly in the case of 'green' buildings (Leaman and Bordass, 2007).

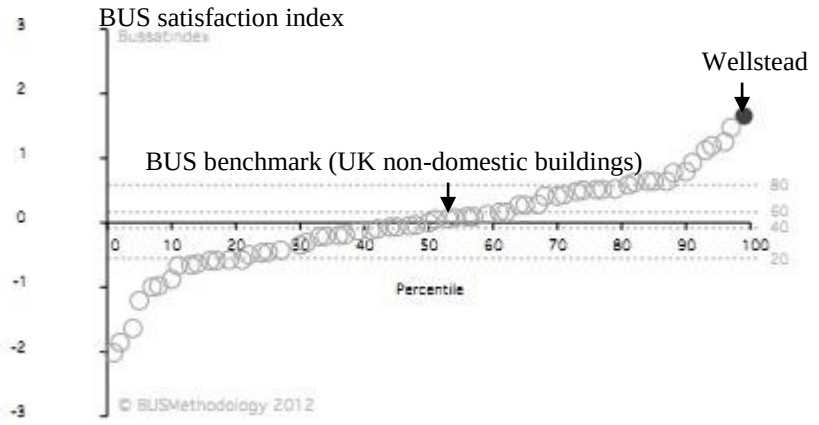


Figure 4.4-1: Satisfaction index regarding the design and the environment of Wellstead School (source: Building Usable Studies).

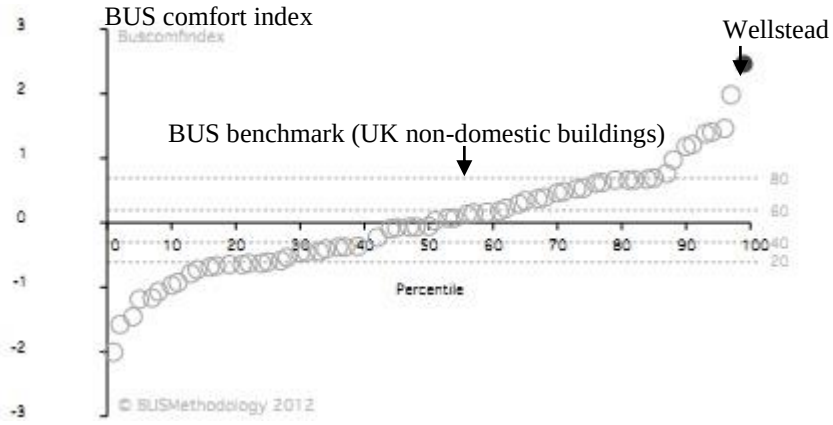


Figure 4.4-2: Comfort index regarding the environment of Wellstead School. (source: Building Usable Studies)

The evaluation of the actual environmental performance as well as the energy performance of the school has revealed several negative environmental aspects of the design. These negative aspects include excessive daylight in classrooms, the overheating problem in the office and slow reaction of the under-floor

heating system. Gaps between the design intent and the actual building performance have inferred that some strategies employed in the school are not coherently interrelated.

In terms of daylighting performance, daylighting sufficiency can be generally achieved in all learning spaces in the school (i.e. southern classrooms) based on the current glazing design, i.e. full-height glazing design and rooflights; however, the occurrence of UDI-e in the southern classroom and the glare analysis indicate that daylighting adequacy, the possibility of excessive daylight and the glare probability should be considered as an integration during the daylighting design process.

On the other hand, as the school was designed to be naturally ventilated all year round, the glazing design and the design of openings are coherent to the factual ventilation efficiency as well as thermal comfort in the school. The prediction of the ventilation performance of a southern classroom reveals the shortcomings in the design of openings, as the required air flow rates to remove excessive heat gains in summer months cannot be achieved by the current outlet. In addition, the on-site measurement of the indoor temperature of the head teacher's office also shows that the small opening in the office will increase the likelihood of excessive heat gains from solar radiation. These indicate that larger outlets in the classrooms and the office are required.

A combination of passive strategies and innovative technologies, such as ground source heat pumps, was applied by the design team to ensure the environmental performance of the school in terms of energy efficiency and carbon emissions. However, the DEC result (i.e. rating D), the annual energy consumption of electricity and gas and the annual carbon emissions denote that

the environmental performance of the school was not as good as the expected. Taking the use of ground-source heat pumps as an example, it was considered as an environmental ‘bonus’ by the architect to minimise carbon emissions of the school. However, the energy bill of the school is quite expensive; this is due largely to this ‘bonus’ of powering the school by electricity. According to the interview with the in-house engineer, the first energy tariff selected for the school was a similar one for a gas-fired school based on the design team’s experience. Consequently, the energy bill for the first-running year of the school was unexpectedly high (Boardman, interview, 11 February 2012).

Learning from Wellstead Primary School, the evaluation results of the school show a gap between the design intention and the actual environmental performance, indicating that designers should have a comprehensive understanding regarding the advantages and disadvantages of the strategies. Simple design tools should be applied more wildly at early design stages, and the involvement of the end users of buildings is essential. Guidance regarding how to use the school should be provided by the design team.

Chapter 5 Building performance assessment

The previous chapter displays a detailed case study of one of the schools studied, indicating the existence of gaps between design intent and actual building performance. Some design-related factors that can influence building performance were inferred from the pilot case study, containing the property of design strategies, collaborations between designers and engineers, as well as after-care service. To further reveal building performance of the schools selected, in this chapter, evaluation results of the technical performance of the five schools are summarised in terms of environmental performance and energy performance, including the pilot case study project. Analyses regarding why several schools did not perform as expected in practice is also involved in the following content.

For environmental performance, three aspects, i.e. daylighting performance, ventilation efficiency and thermal comfort, were assessed for each of the five schools via on-site observation, data collection and computerised simulation. The investigation chiefly focused on whether there is a gap between ‘as designed’ performance and ‘as in use’ performance, assessing building performance from the quantitative aspect. When it comes to energy performance, although energy performance has been considered as an essential to reveal actual building performance (Gupta and Dantsiou, 2013), it was evaluated via a relatively simple manner in this research, i.e. DECs and annual carbon emissions in comparison with relative benchmarks, acting as a supplementary evidence to indicate building performance of the schools. This is due largely to the scope of this research and the limited time allowance. However, it should be concerned as one of the research limitations, and

detailed energy data, such as monthly energy breakdown and meter readings, should have been added into the future work.

5.1 School background

The five case study schools are: School A - Wellstead Primary School designed by HCC Architects, School B - Sandal Magna Primary School designed by Sarah Wigglesworth Architects (SWA), School C - St Luke's C.E. Primary School designed by Architype, School D - Minster School designed by Penoyre & Prasad Architects (P&P) and School E - Chelsea Academy designed by Feilden Clegg Bradley Studios (FCBs). All the five schools received the RIBA Regional Awards from 2008 and 2011, indicating design quality. On the other hand, all these schools received at least the BREEAM rating of 'Very Good', while school C achieved the rating of BREEAM 'Excellent', and hence potentially good sustainable performance.

Detailed design information of the schools studied are attached in Appendix 3, including design intent, site locations, architectural drawings, as well as external and internal images (see Appendix 3: School design information).

Chief design strategies employed in the five schools are summarised in Table 5.1-1. Passive strategies, environmental technologies and building management systems have been widely used in the schools studied, showing that all the five projects were environmentally designed to deliver sustainable learning environment. It is noteworthy that all the schools studied were designed to work 'passively' except School E which mainly relies on mechanical systems to resolve environmental issues.

Table 5.1-1: Environmental design strategies used in the schools studied.

	School A	School B	School C	School D	School E
Daylighting	√	√	√	√	√
Natural ventilation	√	√	√	√	
Mechanical ventilation				√	√
Thermal mass		√			
Ground source heat pumps	√	√			√
Under-floor heating	√	√	√	√	√
Biomass boiler			√		
Photovoltaic panels	√	√		√	
Rainwater collection		√			
BMS	√	√	√	√	√

A: Wellstead Primary School; B: Sandal Magna Primary School; C: St Luke's Primary School; D: Minster School; E: Chelsea Academy

Passive strategies Active strategies Environmental technologies Auto-controls

5.2 Daylighting performance

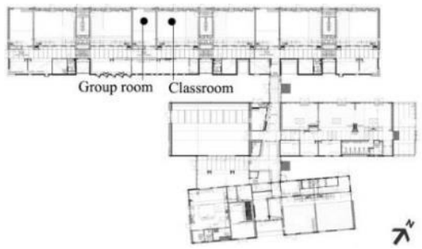
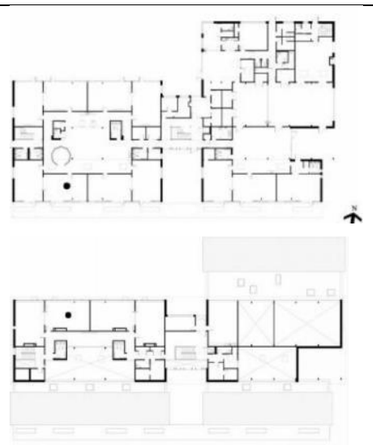
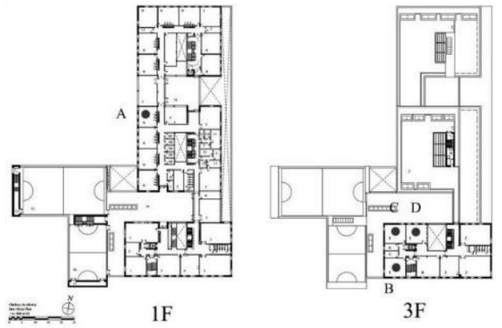
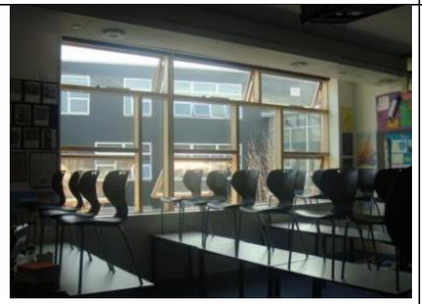
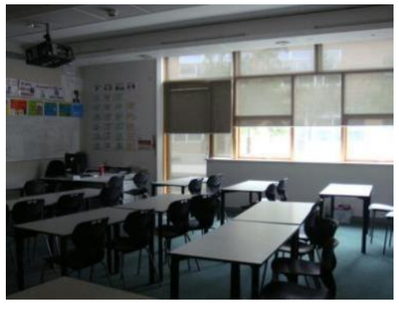
Daylighting has been used as a primary environmental strategy in all the schools studied. As quality daylight has a great impact on improving students' performance, user health and productivity (Heschong et al., 2002), daylighting performance has been deemed as the most essential factor when evaluating environmental performance of schools in this research project.

To assess daylighting performance of the five schools, several learning spaces, i.e. typical classrooms with different orientations, were picked from each of the schools as the representative objects, shown in Table 5.2-1. Photos attached were taken from on-site visits, recording the lighting environment of the classrooms studied under overcast sky conditions. Artificial lighting was

switched on in several classrooms, such as School B and D, showing inadequate daylight. In addition, the average daylight factors (DF) calculated based on the on-site illuminance measurement are displayed in the table, indicating that several classrooms studied, such as the classrooms from School B, D and E may have daylighting problems i.e. daylight insufficiency.

Except the on-site illuminance measurement undertaken for overcast sky conditions, further computerised simulation was conducted to evaluate daylighting performance under different sky conditions. As mentioned previously in the pilot case study, the programme, DAYSIM, was used to calculate the hourly internal illuminance at each testing point within the selected spaces, i.e. the classrooms marked on Table 5.2-1, using the weather file of the CIBSE Test Reference Year (TSY) for Southampton, Leeds, Wolverhampton, Nottingham and London, respectively. The simulation provides more reliable results based on 'real' conditions. DA and UDI metrics were calculated as key parameters to indicate daylighting sufficiency as well as daylighting quality, in accordance with the current orientation and glazing design. In addition, analyses regarding the luminance ratios in the classrooms were specifically conducted to assess the visual discomfort levels. The DA and UDI results of all the classrooms simulated via DAYSIM are summarised in Table 5.2-2, in comparison with the latest Baseline Design for Schools (BDFS) 2014. Detailed simulation process and the corresponding results shown on figures can be found in Appendix 4.

Table 5.2-1: The representative classrooms selected for daylighting assessment and the corresponding daylight factors.

School A	School B	School C	School D	School E
				
Orientation: Southwest	Orientation: Northwest	Orientation: GF – south; 1F – north	Orientation: GF – north and south	Orientation: 1F – west; 3F – north, south
 	 	 	 	 
Average DF: 5.95%	Average DF: 3.28% (classroom), 4.1% (group room)	Average DF: 5.63% (north), 5.85% (south)	Average DF: 3.95% (north), 3.23% (south)	Average DF: 4.12% (west), 3.95% (south), 3.25% (north)

According to *BDFS* 2014, UDI (between 100 and 3,000 lux) should be achieved in at least 80% of the working year for all learning spaces and sDA should be no less than 50% (EFA, 2014). All the classrooms evaluated should have reached the standards, as the schools studied were environmentally designed and the efficiency of the environmental strategies employed should have been assessed by the design teams during the design process. However, it can be seen from Table 5.2-2 that the classrooms in School B, D and E did not perform as well as expected, particularly for the classrooms in School B and E. The UDI achieved in School B, D and E were generally lower than 80%, implying the issue of daylight insufficiency. Additionally, the values of $sDA_{300/50\%}$ achieved in School B, D and E which are mostly fewer than 50%, and hence the issue of uneven daylight distribution.

Table 5.2-2: Summary of UDI and DA results of the cases studied.

Case studied	Classroom orientation	Daylighting performance (Assessment results)		
		$UDI_{100\text{-}3,000}$	DA_{300}	$sDA_{300/50\%}$
School A	Northwest	87.9%	84.6%	95%
School B	Northwest	**76.4%**	41.5%	**27%**
	Northwest	83%	50.6%	**44%**
School C	North	81%	68.3%	95%
	South	81.7%	69.2%	100%
School D	North	83.5%	52.3%	**37%**
	South	**71%**	51.9%	55%
School E	West	80%	69.2%	100%
	North	**68.1%**	32.3%	**35.7%**
	North (near atrium)	**75.4%**	44.2%	**44.6%**
	South	**71.6%**	47.1%	50.8%
BDFS	Typical	≥ 80%	N/A	≥ 50%

In the following content, the evaluation results of daylighting performance of

the case study projects are displayed, focusing on the aspects of daylight sufficiency, daylight distribution and the possibility of visual discomfort.

5.2.1 School A

Generally, quality daylight can be provided in school A in terms of daylight adequacy and balanced distribution. However, the occurrences of excessive daylight which can lead to visual discomfort or interrupt learning activities were revealed in accordance with the evaluation results. To solve this problem, shading protection was suggested to be improved. Detailed daylighting analysis about the classroom chosen from School A can be found in Section 4.2.1.

5.2.2 School B

For the two learning spaces evaluated in School B (Sandal Manga Primary School), i.e. a typical classroom and a group room facing the northwest, one of the daylighting issues revealed from the DA and sDA assessment was *daylight insufficiency*. Based on the calculation results of the average DA_{300} (i.e. 41.5% and 50.6% for the classroom and the group room, respectively) and $sDA_{300/50\%}$ for the classroom (27%) and the group room (44%), it can be found that, on average, the areas under analysis in both the spaces can receive at least 300 lux in *less* than half of the daylight working year. In addition, only 27% of the working plane in the classroom and 44% of the working plane in the group room can receive at least 300 lux in more than 50% of the working hours. According to *CIBSE Guide A Environmental Design* (2015) and *BDFS* 2014 (EFA, 2014), it can be inferred that the two learning spaces studied can hardly achieve daylight sufficiency simply based on the current glazing design, from both the time and spatial aspects.

On the other hand, the UDI indexes distribution for the classroom and the group room displayed on Figure 5.2-1 and Figure 5.2-2 further highlight the issue of daylight inadequacy while pointing out the existence of *uneven daylight distribution*. In Figure 5.2-1 and Figure 5.2-2, the dark green line represents the occurrence of UDI-a (i.e. between 300 and 3,000 lux) distributed over the working plane; and the light green line and the yellow line represent the distribution of UDI-s (i.e. between 100 and 300 lux) and UDI-f (i.e. less than 100 lux), respectively. It can be seen from the graphs that the occurrences of UDI-a in both of the rooms obviously decrease from the areas near the northern glazing to the centre of the rooms. It shows that, unquestionably, artificial lighting is demanded for more than half of the working year in the rooms to ensure the required illuminance levels, particularly for the centre of the rooms. This finding did not match the design intent of maximising daylight, even though the southeast-facing rooflights employed for the classroom and the northwest-facing clerestory windows installed for the group room did provide certain improvements to the values of UDI-a at the back of the spaces.

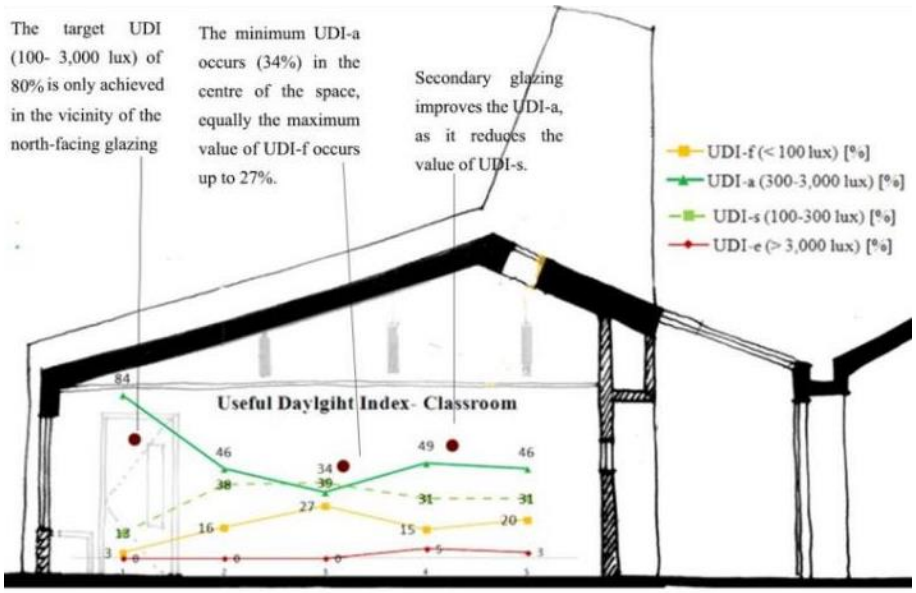


Figure 5.2-1: UDI index of the classroom shown on a section (source: Author).

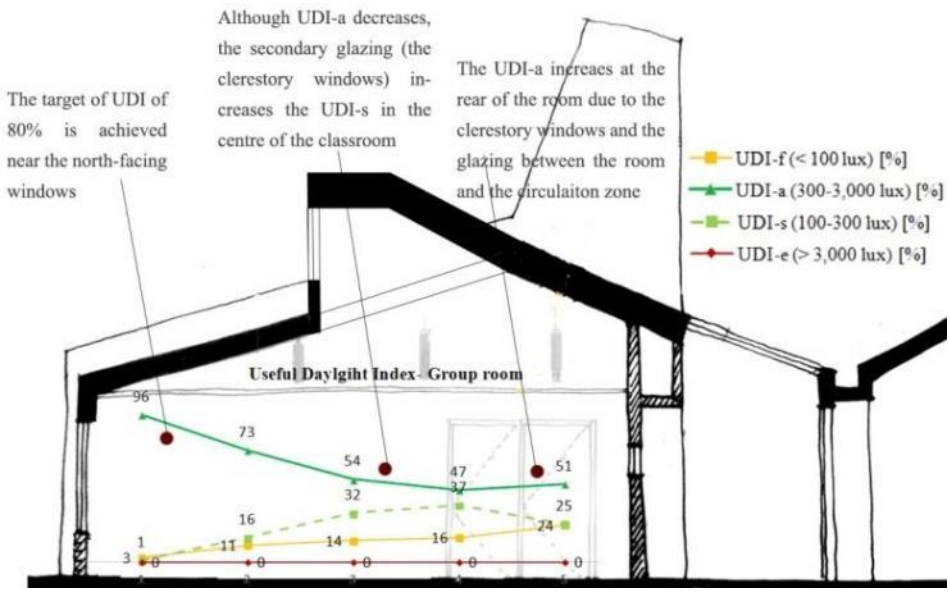


Figure 5.2-2: UDI index of the group room shown on a section (source: Author).

According to Reinhart and Loverso (2010), the chief factors causing daylight insufficiency in School B were related to the *facade orientation*, *the property of the fenestration design* and *the interior finish*. For the main learning spaces in School B, the main building orients towards the northwest (refer to Table 0-1 in Appendix 3). Even though natural light coming from the north can provide even daylight to benefit learning activities such as reading and writing, Table 0-1 in Appendix 4 shows that the northwest elevation of School B is almost shaded by the building block itself during the whole year round, and hence influencing effective daylight.

For the current fenestration system of the learning spaces, it consists of the glazing on the northwest elevation which plays the main role to provide daylight, the rooflights facing the southeast, as well as the clerestory windows facing the northwest, which act as the secondary daylight source to bring daylighting into the back of the classroom and the group room (see Figure 5.2-3). However, for the main daylight source, the window-to-wall ratios

(WWR) of the classroom and the group room, i.e. 0.32 and 0.36 respectively, were considered too inadequate to provide sufficient daylight in accordance with the DAYSIM simulation results. The timber panels inserted between the windows on the northwest elevation were considered to prevent certain levels of natural light. Thus, they were suggested to be replaced by glazed areas.

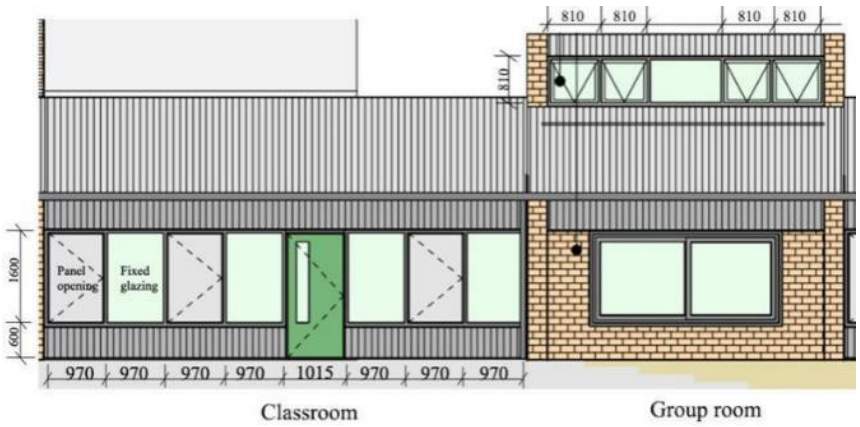


Figure 5.2-3: Glazing design for the classroom and the group room on the northwest elevation (source: SWA).

Besides the facade orientation and the fenestration design, the interior finish of School B was deemed as another factor impacting on daylighting quality. The designers exposed bricks and timber panels as the interior finish, intending to use thermal mass to benefit thermal environment while reducing energy use for heating. Additionally, the acoustic panels overhung were designed to act as a learning tool for students to understand how the school works sustainably (see Figure 5.2-4). However, these strategies caused the interior materials with relatively low reflectance, and the acoustic panels can block daylight from rooflights to a certain degree. Hence, daylight quality can be affected negatively.



Figure 5.2-4: Interior finish of the classrooms: interior materials with low reflectance (source: Author).

The third daylighting issue revealed from the on-site observation was related to the classroom's internal luminance levels. Reading from the following photos taken on site in an afternoon in October 2012 (see Figure 5.2-5), the contrast of the luminance level between the daylight source (i.e. the northern glazing) and the surrounding surfaces was obvious when artificial lighting was off, and this could lead to visual discomfort easily. To investigate the possibility and frequency of visual discomfort in the classrooms, the luminance levels of the vision task (i.e. whiteboard) and the surrounding surfaces in the defined classroom were calculated in the Radiance program at nine representative moments (see Table 0-2 in Appendix 4). In the simulation, the position of an observer is shown in Figure 5.2-6, and the simulation results were shown as luminance false colour images attached in Appendix 4.



Figure 5.2-5: Comparison of the internal luminance levels of a classroom - with and without artificial lighting (source: Author).

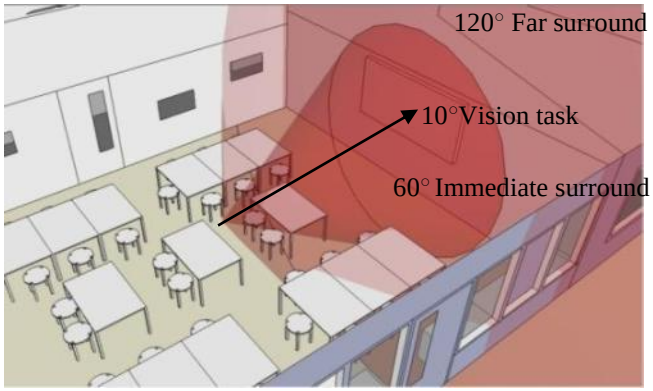


Figure 5.2-6: The visual range set in the classroom (source: Author).

The ratios of the luminance of the task to the immediate surroundings and to the far-surround background at nine representative moments in a year are listed in Table 5.2-3. In general, the luminance levels of the whiteboard are slightly higher than those of the ambient surroundings, which is beneficial to helping observers focus on the task. However, the luminance level of the whiteboard is too low to support the task requirement, particularly in the winter, i.e. less than 100 cd/m^2, emphasising the issue of inadequate daylight. For the ratios of the luminance of the task to the far-surround background, general ratios exceed the rule of thumb 1:10, and hence the existence of harsh contrasts in the view range of the observer. It can be, therefore, inferred that in the classroom visual discomfort often exists when artificial lighting is off, and learning activities can be affected.

Visual discomfort caused by the harsh contrast in School B was due largely to the interior surfaces with low reflectance i.e. the exposed bricks and timber panels (refer to Figure 5.2-4). Additionally, as no shading strategy such as internal blinds was provided, the luminance contrast could exist in classrooms frequently when no extra lighting is provided.

Table 5.2-3: Summary of luminance ratios along the viewing route in the classroom.

Time		Task-to-immediate surroundings	Task-to-far-surround background
Summer solstice	9 a.m.	1: 0.7	**1: 11**
	12 a.m.	1: 0.6	**1: 12**
	3 p.m.	1: 0.7	**1: 11**
Equinox	9 a.m.	1: 0.6	**1: 13.2**
	12 a.m.	1: 0.5	**1: 10**
	3 p.m.	1: 0.7	1: 7.6
Winter solstice	9 a.m.	1: 0.6	**1: 12.3**
	12 a.m.	1: 0.6	**1: 11.9**
	3 p.m.	1: 0.75	1: 7.3

- Summary of School B's daylighting performance

The daylighting analysis in terms of DA, UDI metrics and luminance ratios identifies the chief issue of daylighting in the school – that of insufficient daylight, particularly in the northern learning spaces, i.e. classrooms and group rooms.

The results of DA and UDI metrics in the selected classroom show that the current orientation of the building as well as the glazing design of the classrooms cannot provide adequate daylight illuminance on the working plane, even though the south-facing rooflights can offer a slight improvement to the illuminance levels at the rear of the classrooms. For the group room, although the average UDI achieves above 80% which corresponds to the Baseline design requirement, the minimum value of UDI-a in the centre of the room (i.e. less than 50%) indicates that daylight is not well distributed across the group room, therefore resulting in unbalanced distribution of daylight. On the other hand, the obvious contrast between the luminance of the daylight source and the

surroundings in the classroom can also cause visual discomfort to the users, and this is due largely to the fact that no shading is provided as well as the relatively dark colour of the interior materials with subsequent low reflectance.

To improve the daylighting performance of the school, the glazing design in the learning spaces should be improved. According to the daylighting analysis, it can be inferred that larger glazing areas are required in the learning spaces. The timber panels used in the classrooms are suggested to be replaced by glazing with internal shading attached, in order to maximise the internal daylight while avoiding the glare risk. In addition, the colour of the interior materials employed in the learning spaces could be changed into lighter colours for higher reflectivity. The metallic hangings on top of the learning spaces could have been adjusted or removed in order to improve the reflective daylight inside of the learning spaces.

5.2.3 School C

According to the on-site illuminance measurement and the DAYSIM simulation results, School C achieved satisfactory daylighting performance, particularly in terms of daylight sufficiency and balanced distribution of natural light. Two classrooms orienting in different directions were selected as the key evaluation objects to represent daylighting performance of School C - one is a south-facing classroom on the ground floor and the other is a north-facing classroom on the first floor. Different daylighting strategies were employed by the designers for the classrooms with different orientations. Positions of the classrooms studied can refer to Table 5.2-1.

Based on the DA and sDA results, on average, all the areas under analyses in

the two classrooms can receive at least 300 lux in approximately 70% of the daylight working hours (per year), assuring adequate daylight illuminance to support common teaching/learning tasks, from both the time and spatial aspects. This finding corresponds to the distribution of DA_{300} on the analysis planes that the differences of DA_{300} across the analysis planes are not obvious, apart from the significant dip in illuminance levels in the areas near the edges of the analysis planes caused by the block of columns. The DA_{300} distribution in the classrooms can be seen in the 3D graphs displayed in Table 0-4 in Appendix 4.

Besides the values of DA and sDA, the average values of UDI-a in the northern classroom and the southern classroom are 81.4% and 83.5%, respectively. These values achieved the *BDFS* 2014 standards, indicating that useful levels of daylight illuminance (i.e. between 100 lux and 3,000 lux) can be provided on the working planes at most times of the working year, and hence maintaining learning activities without the supplementary artificial lighting. The graphs in Figure 5.2-7 and Figure 5.2-8 display the UDI indexes distribution for the specified classrooms, which also correspond to the previous findings regarding daylight adequacy. In addition, they demonstrate that the daylighting strategies employed, i.e. the large glazing design for both the classrooms and the clerestory windows for the southern classroom, therefore have maintained a very evenly day-lit environment with excellent natural light distribution.

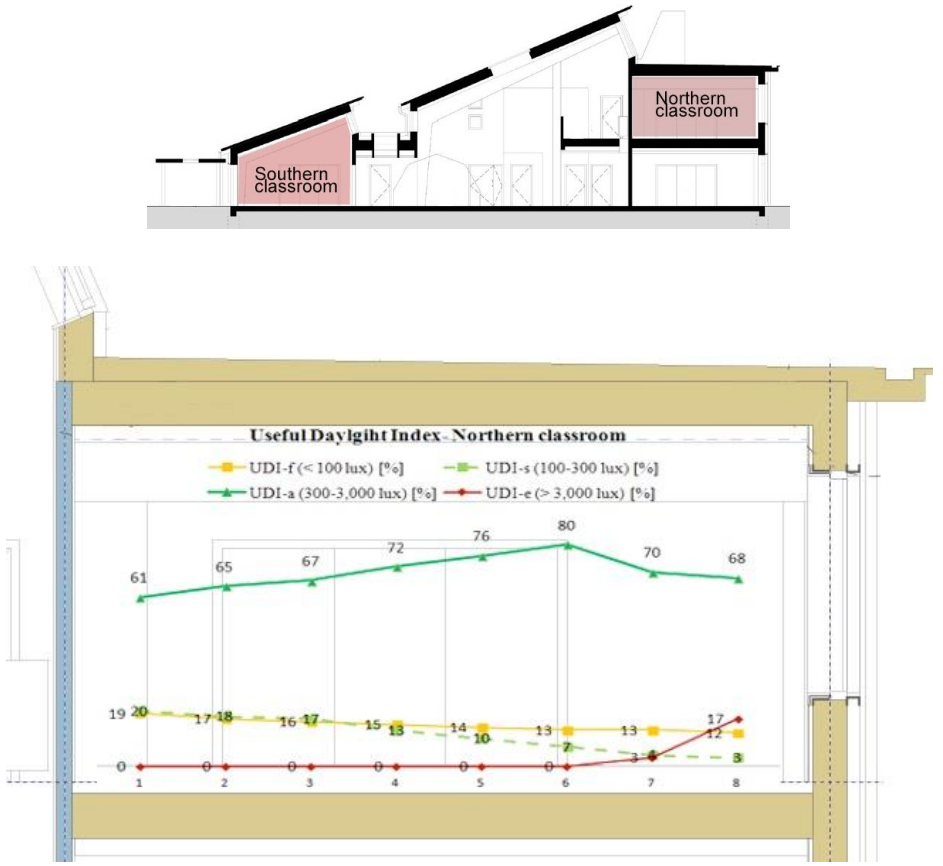


Figure 5.2-7: UDI index of the northern classroom in school C shown on a section (source: Author).

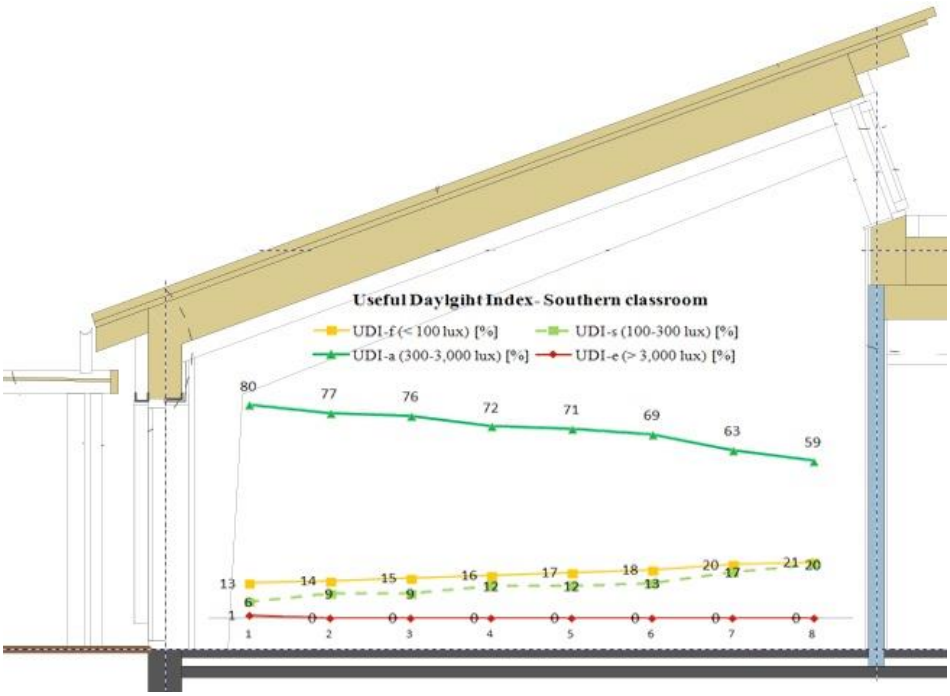
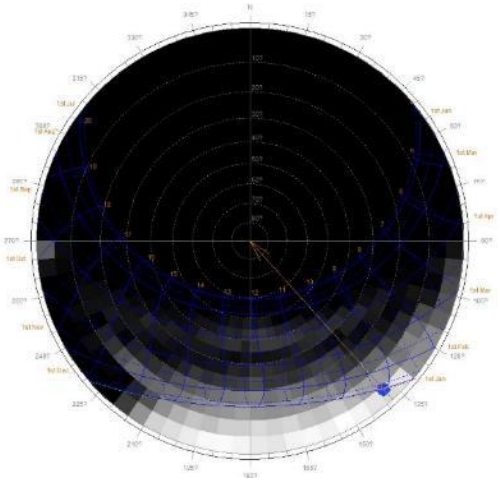


Figure 5.2-8: UDI index of the southern classroom in school C shown on a section (source: Author).

Although quality daylight has been proved in School C, the possibility of direct sunlight which can produce the risk of glare was revealed from the classroom's shading analysis in Ecotect. Figure 5.2-9 illustrates that sunlight at the winter solstice can enter the southern classroom most of the school hours, implying that low-angle sunlight in the winter months can enter the southern classrooms without sufficient protection, even though the external canopy is attached. This could cause reflections off surfaces, and hence leading to visual discomfort.



Time	Shading percentage
9:00	14%
10:00	20%
11:00	40%
12:00	41%
13:00	42%
14:00	55%
15:00	85%

Figure 5.2-9: Solar penetration of the southern classroom at the winter solstice: with external canopy (source: Ecotect).

Further analysis regarding the luminance conditions of classrooms at nine representative moments in a year was conducted in Radiance, and the corresponding results are displayed in Table 5.2-4. The observer's position for the simulation of luminance levels in the classroom is shown in Figure 5.2-10.

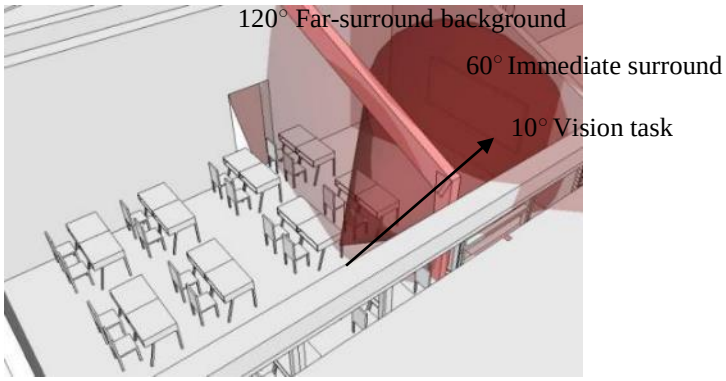


Figure 5.2-10: The visual range set in the model of School C (source: Author).

Table 5.2-4: Summary of luminance ratios along the viewing route in the classroom of school C.

Time		Task-to-immediate surroundings	Task-to-far-surround background
Summer solstice	9:00 a.m.	1: 1.4	**1: 11.7**
	12:00 p.m.	1: 1.6	**1: 12.3**
	15:00 p.m.	1: 1.5	**1: 11.2**
Equinox	9:00 a.m.	1: 1.7	**1: 14**
	12:00 p.m.	1: 1.8	**1: 10.8**
	15:00 p.m.	1: 1.8	1: 7.3
Winter solstice	9:00 a.m.	1: 1.7	**1: 25.3**
	12:00 p.m.	1: 1.6	1: 4.3
	15:00 p.m.	**1: 8.5**	**1: 11.7**

The simulation results show that, in general, the luminance levels of the whiteboard are slightly lower than those of the ambient surroundings, which could distract observers from focusing on the task (Detailed data can be found in Table 0-5 in Appendix 4). An extreme (i.e. 1: 8.5) occurs during the afternoon at the winter solstice due to reflections off the immediate surfaces from direct sunlight.

For the ratios of the luminance of the task to the far-surround background,

general ratios are greater than the rule of thumb 1:10, particularly the luminance contrast at 15:00 p.m. at the winter solstice is very obvious (see the false colour representations for winter solstice in Table 0-6). As a result of the large ratios of the luminance of the task surface to the luminance of the non-adjacent background, the probability of visual discomfort due to evident luminance contrast can be assumed on sunny days in summer and winter. Additionally, the harsh reflections from visual tasks revealed from the false colour map can easily decrease the effectiveness of the interactive whiteboard, and hence affecting the observer's productivity. The luminance false colour images can refer to Table 0-6. This phenomenon matches the previous shading analysis for the southern classroom that low-angle sunlight can enter classrooms and lead to the possibility of glare in winter, and also reflects the occupant feedback regarding daylighting in the southern classrooms.

- Summary of School C’s daylighting performance

The daylight analysis proves the effectiveness of the design of the fenestration system of School C in terms of delivering sufficient daylight. The DA and UDI results indicate that the designers show real understanding of daylighting issues and created an excellent and well-distributed daylight environment in the studied school. The strategies employed in terms of the window size, central atrium and high-level clerestory windows for the southern classrooms work effectively to maintain a well daylit environment for teaching/ learning activities. The lighting environment of the school also received very positive appraisals from the school users.

Although the daylighting design in the school achieves a success in terms of daylight adequacy and distribution, the limitations of the glazing design and the

shading strategies employed were revealed by the certified possibility of glare and visual discomfort. For the southern classrooms, the existing daylighting issues are chiefly due to inefficient shading strategies, which can be improved in the future by adding internal blinds.

5.2.4 School D

For School D, the daylighting environment of the main learning spaces, i.e. the eastern classroom 'fingers', would vary due to different orientations in accordance with the site's solar analysis, as the north-facing classrooms in the three classroom 'fingers' are almost shaded by the building massing throughout the whole year and the south-facing classrooms are generally exposed to solar radiation without shading protection (see Table 0-7 in Appendix 4). Two classrooms with different orientations were therefore selected as the monitored objects to represent daylighting performance of School D. Locations of the selected classrooms are shown in Table 5.2-1, i.e. the ground floor, in the middle 'finger'.

According to the simulation results, different daylighting issues were revealed in the two classrooms. For the northern classroom, the chief issue was related to daylight distribution. The average value of UDI-a in the northern classroom achieves 83.8%, assuring daylight adequacy to a certain degree. However, the value of $sDA_{300/50\%}$ in the classroom (i.e. 48%) indicates that there is *less* than half of the area under analysis in which can receive at least 300 lux more than 50% of the working hours, and hence uneven daylight distribution. This finding was further proved by the UDI indexes shown on the section of the northern classroom (see Figure 5.2-11). It can be seen fromFigure 5.2-11 that the occurrences of UDI-f (i.e. represented by the yellow line) and UDI-s (i.e.

represented by the light green line) increase evidently from the area near the northern window to the back of the classroom. Consequently, the rare of the northern classroom can hardly achieve a quality lighting environment when the artificial lighting is switched off.

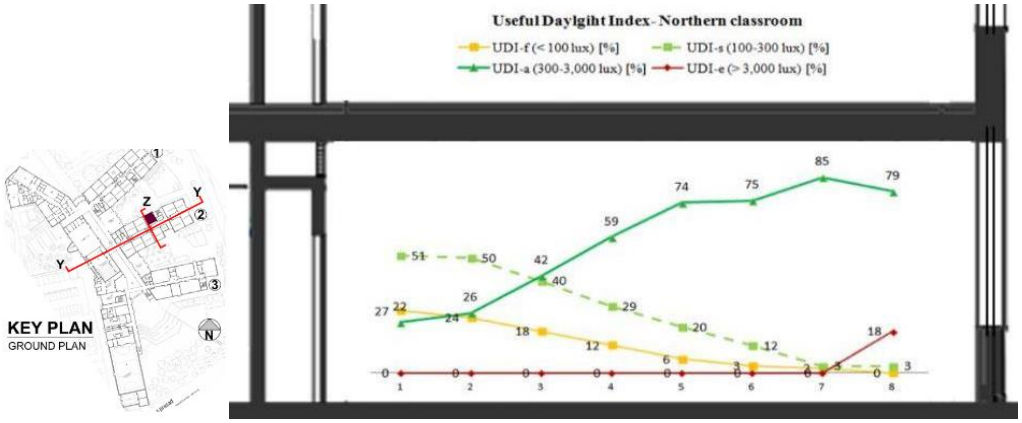


Figure 5.2-11: UDI index of the northern classroom (School D) shown on section Z (source: Author).

For the southern classroom, the average value of UDI i.e. *69.9%* did not achieve the BDFS 2014 standard, implying the chief daylighting issue – daylight insufficiency. The significant fluctuation of UDI-a distributing across the classroom and the distribution of UDI-f prove that artificial lighting is necessary to maintain the required daylight illuminance, particularly for the back of the classroom; hence daylight distributed unevenly (see Figure 5.2-12). Additionally, the occurrences of UDI-e (i.e. represented by the red line) indicate that excessive daylight can frequently occur on the working plane near the southern glazing (refer to the 3D graphs of UDI-e for the southern classroom in Table 0-8), which can cause the overheating problem in summer, as well as visual discomfort. To prevent the risk of excessive daylight, internal blinds can be used, but in accordance with the staff's feedback regarding the use of internal blinds that "*they are too thin to block sunlight from the outside*" (Staff, survey, March 2012), the risk of excessive daylight in the southern

classrooms can be confirmed.

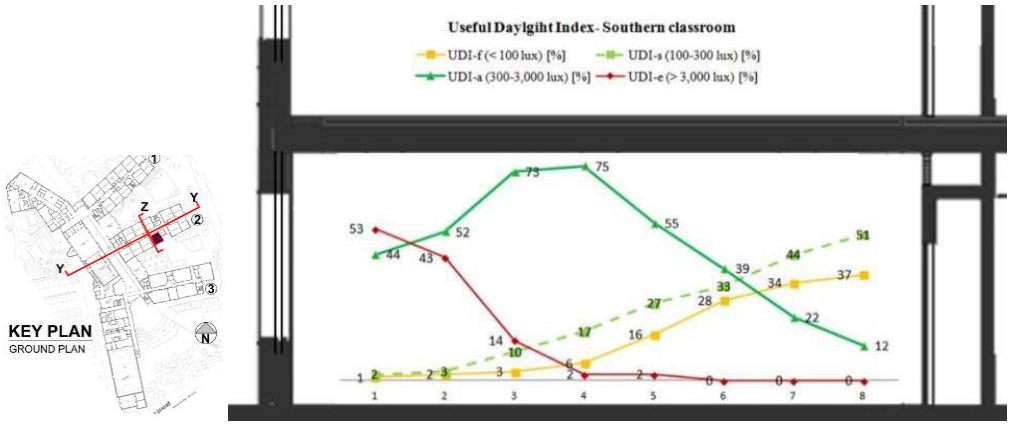


Figure 5.2-12: UDI index of the southern classroom (School D) shown on the section Z (source: Author).

The above daylighting issues revealed from the UDI and DA analyses were mainly caused by the combination of facade orientations and the design of fenestration systems. The school's building mass – three classroom 'fingers' – provide solar shading to each other, to a certain degree (see Table 0-7). Thus, for the classrooms with different orientations, the qualities of daylight that can be achieved are also different. However, the window designs in terms of glazing size and positions are similar. In addition, same shading devices, i.e. internal adjustable blinds, are applied to both southern and northern classrooms. For the southern classrooms in which revealed the occurrences of excessive daylight, external shading strategies were not supplied.

In accordance with the above UDI-e analysis, it can be assumed that occupants who use the southern classrooms are more likely to experience visual discomfort due to the comparatively higher occurrences of UDI-e. Thus, the southern classroom in the previous UDI analysis was selected as the research object to assess the possibility that visual discomfort would occur. For this assessment, the luminance ratios of a whiteboard to the surroundings were

measured in the Radiance program, to investigate whether visual discomfort exists when the occupants look at the whiteboard in the southern classroom. An observer's position was set in the centre of the classroom (see Figure 5.2-13).

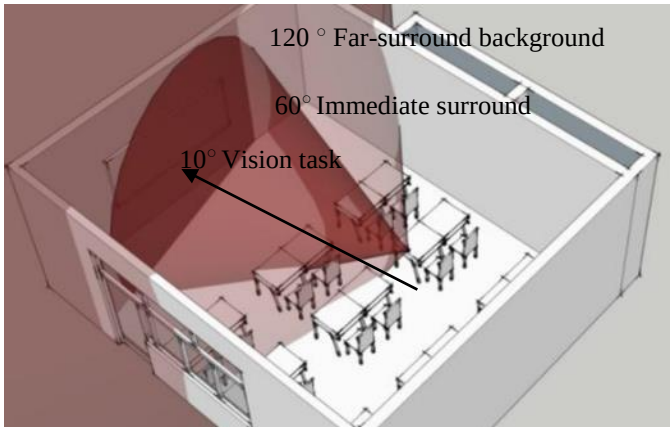


Figure 5.2-13: The visual range set in the model (source: Author).

According to the simulation results representing in Table 0-8 and 0-9 (in Appendix 4), the average luminance of the whiteboard varies from the lowest of 19 cd/m^2 to the highest, of about 700 cd/$m^{2,}$ at different times of a year. The large differences indicate the variable luminance levels of the vision task; hence leading to negatively impact to the use of the interactive whiteboard. The lowest luminance values occur at the winter solstice, implying less daylight can enter the southern classrooms during the winter months when the solar angle is low, corresponding to the findings of the solar shading analysis (refer to Table 0-7). It was mainly caused by the building mass and facade orientations.

On the other hand, Table 5.2-5 which shows the ratios of the luminance level of the task to the immediate surroundings and to the far-surround background exhibits that, in general, the luminance levels of the whiteboard are lower than those of the ambient surroundings. This phenomenon can distract observers focusing on the task when no electrical light is provided, due largely to

insufficient daylight based on the current daylighting design. Two exceptions of luminance ratios (i.e. the ratios exceed the rule of thumb 1:3) occur in the morning (9:00 a. m.) in the equinox and the winter solstice, and this was caused by harsh reflections from direct sunlight off the immediate surfaces.

Table 5.2-5: Summary of luminance ratios along the viewing route in the classroom.

Time		Task-to-immediate surroundings	Task-to-far-surround background
Summer solstice	9:00 a.m.	1: 2	**1: 45**
	12:00 p.m.	1: 1.6	1: 4
	15:00 p.m.	1: 2.1	1: 8.9
Equinox	9:00 a.m.	**1: 20**	**1: 17**
	12:00 p.m.	1: 1.1	1: 1.8
	15:00 p.m.	1: 1.6	1: 7.6
Winter solstice	9:00 a.m.	**1:3.9**	**1: 11.7**
	12:00 p.m.	1: 2	1: 8.6
	15:00 p.m.	1: 1.9	**1: 10.8**

For the ratios of the luminance of the task to the far-surround background, four ratios are above the rule of thumb 1:10, and the three of the four were measured at the morning period in the summer solstice, the equinox and the winter solstice. Although higher luminance ratios can be tolerated by observers due to the glazing that can be seen within the view range, the harsh reflections off the task surface and the ambient surroundings in the morning periods at the summer solstice and the equinox (displayed in Table 0-10) prove the existence of visual discomfort in the southern classroom due to the glazing design. Proper shading such as external horizontal shading or internal blinds can mitigate against this risk; however, no external shading was provided and the building users reported that the internal blinds were "*not working properly*". Hence, teaching/learning activities can be easily interrupted by this visual

discomfort.

- Summary of School D's daylighting performance

The daylight analysis of the two classrooms with different orientations point out the limitations of the glazing design for learning spaces in School D. The existing daylighting issues in terms of daylight insufficiency and unbalanced daylight distribution are chiefly due to the glazing design for classrooms. The same size glazing is applied for all standard classrooms in the school, irrespective of the direction in which they are oriented, even though the glazing with lower solar transmission value was chosen for the south-facing windows.

The DA and UDI analysis of the specified classroom denotes that both the classrooms cannot receive sufficient daylight based on the current glazing design. In detail, the daylighting performance in terms of daylight adequacy in the northern classroom is slightly better than that of the southern classroom, but daylight in the southern classroom distributes more evenly than it in the northern classroom. In addition, the occurrences of UDI-e and the luminance ratios of the luminance of the whiteboard to the surroundings in the southern classroom reveal the high risk of visual discomfort in the southern classroom, which is due largely to the size of the glazing as well as the less effective internal blinds. The risk of visual discomfort in classrooms and the issue of daylight insufficiency can be addressed by daylighting performance simulations at the design stages. Furthermore, environmental consultancy should have made suggestions for the glazing design of the learning spaces based on the room size and orientation.

5.2.5 School E

The chief issue related to daylighting design in School E is how the designers deal with the implications of east and west orientation. To test whether or not quality daylit environment can be achieved based on the provision of current daylighting strategies, four classrooms that have different orientations and fenestration design were selected as research objects to represent daylighting performance of school E. The location of the selected classrooms can refer to Table 5.2-1.

In the four classrooms studied, classroom A is located on the first floor in the middle cluster so that its daylight source chiefly comes from the single-sided windows on the western façade. Classroom B located on the third floor in the southern cluster can be daylit by the two-sided windows on the southern and the western façades. Classrooms C and D are on the same floor as classroom B, and mainly orient towards the north, although Classroom D is particularly linked to an atrium space. As a result, classroom D can receive daylight either from the northern windows or from the glazed areas between the classroom and the atrium.

Based on the DA and sDA analyses, classroom A and B achieved relatively satisfactory performance in terms of daylight sufficiency and balanced daylight distribution. However, for the two northern classroom (i.e. classroom C and D), the issues of inadequate daylight and uneven daylight distribution were revealed in accordance with the DA_{300} distribution in the classrooms and the values of $sDA_{300/50\%}$ shown in Table 0-11 in Appendix 4.

In accordance with the average DA_{300} values of the four classrooms (i.e. 69.2%, 52.4%, 32.3% and 44.2% for classrooms A, B, C and D, respectively) and the

values of $sDA_{300/50\%}$ (i.e. 100%, 50.5%, 35.7% and 44.6% for classroom A, B, C and D), it can be inferred that classroom C and D (i.e. northern classrooms) suffer from insufficient daylighting over half of the working year for general teaching activities. Artificial lighting is, therefore, certainly demanded for the northern classrooms based on the current design of fenestration systems. This issue was due largely to the insufficient provision of daylight source, i.e. the design of fenestration systems. Based on the current fenestration design on the northern facade (see Table 5.2-6 and Figure 5.2-14), very limited glazing was supplied to classroom C – one window is located on the western facade and the other is located on the northern facade matching the facade's 'pattern'. It seems that the designers paid more attention to the aesthetic factor of facade design, while sacrificing daylighting opportunities to a certain degree.

Table 5.2-6: Dimensions of the selected classrooms in school E and their fenestration design.

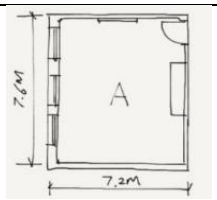
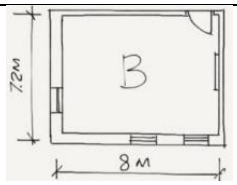
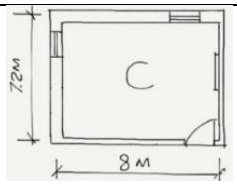
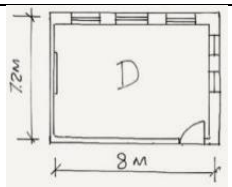
	Dimension	Fenestration design
Classroom A		Chief orientation: west Window numbers: 3 Single-sided
Classroom B		Chief orientation: south Window numbers: 3 Double-sided – 2 (southern); 1 (western)
Classroom C		Chief orientation: north Window numbers: 2 Double-sided – 1 (northern); 1 (western)
Classroom D		Chief orientation: north Window numbers: 5 Double-sided – 3 (northern); 2 (next to the central atrium)



Figure 5.2-14: The fenestration design for classrooms C and D on the northern facade (source: Author).

On the other hand, the UDI analysis further demonstrates that only classroom A, which orients the west, can provide useful illuminance on the working plane in most of the working year, while pointing out that the daylighting strategies used for classrooms B, C and D in the southern cluster do not completely provide a sufficient and effective daylighting environment for general teaching activities. This result generally corresponds to the previous finding based on the DA and sDA analysis. In addition, the occurrences of excessive daylight in the western classroom (classroom A) and the southern classroom (classroom B) were highlighted in accordance with the UDI-e analysis. Relevant results of UDI indexes are presented in Table 0-12 and Table 0-13 in Appendix 4.

Based on the UDI analysis, comparison between the daylighting performance of classroom C with classroom D shows that the glazing between classroom D and the atrium offered a certain improvement in daylighting in terms of the reduction of the occurrences of UDI-f. Nevertheless, it can be assumed that the central atrium did not obviously contribute to the daylighting performance of the surrounding classrooms, as the achievement of UDI in classroom D is still below 80%. Detailed information can be seen in the false colour maps of UDI, UDI-e and UDI-f of the four classrooms displayed in Table 0-13.

According to the UDI analysis, the possibility of the risk of glare was identified in the western classrooms and the southern classrooms. Thus, the analysis of visual discomfort and possibility of glare was conducted for classroom A and B.

The site-shading analysis (see Table 0-14) indicates that school E can receive solar radiation directly from the south in summer months when direct sunlight should be avoided. This reflects the previous UDI findings for classroom B - that UDI-e near the south-facing windows can reach up to 40%. For the western elevation, direct sunlight can reach it without any external shading during afternoon periods in almost the whole year, particularly in the winter months when the solar angle is low. Thus, it can be inferred that for the western classrooms, *the possibility of glare as well as the overheating issue due to direct sunlight is quite large*, although the thickness of the external walls, i.e. 600mm, can act as external ‘shading’ for the classrooms to a certain degree, and the installed blinds can be manually controlled if necessary. However, this could also risk a 'blinds down- lights on' syndrome in classrooms which can be seen in Figure 5.2-15.



Figure 5.2-15: The phenomenon of 'blinds down- lights on' in a classroom of school E (source: Author).

A further simulation using the Radiance program was carried out for classroom

A in terms of the luminance ratios of the whiteboard to the surroundings in order to investigate whether the occupants (i.e. students) in the western classroom will suffer visual discomfort when looking at the white board. An observer's position was set in the centre of the classroom (see Figure 5.2-16).

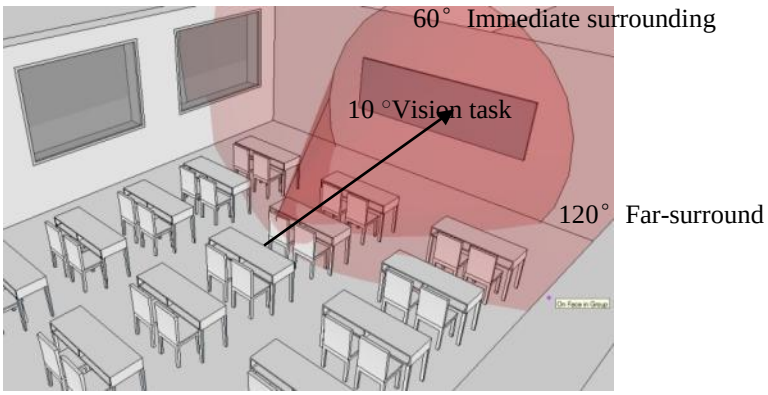


Figure 5.2-16: The visual range set in the model of classroom A in school E (source: Author).

The related simulation results are presented in Table 0-15 and Table 0-16 in Appendix 4. Reading from Table 0-15, the average luminance of the whiteboard clearly varies at different times in a year, i.e. between 230 and 1192 cd/m^2. Normally, in the morning periods, the luminance level of the whiteboard is much lower than it is in the afternoon periods due to solar angles. In addition, it is noteworthy that there is an obvious contrast between the luminance levels of the vision task (i.e. the whiteboard) and its surroundings in the afternoon periods, particularly at the equinox and winter solstice. This obvious contrast of luminance can easily cause visual discomfort to the occupants, hence affecting their working productivity.

Table 5.2-7 shows the ratios of the luminance of the task to the immediate surroundings and to the far-surround background. In general, the luminance levels of the whiteboard are similar to those of the ambient surroundings, and the luminance ratios are all within the rule of thumb of 1:3. For the ratios of the

luminance of the task to the non-adjacent background, severe contrast does not exist (i.e. all within 1: 10). However, as per the luminance images and the corresponding false colour maps of the afternoon periods in the equinox and the winter solstice (see Table 0-16), the existence of luminance difference between the white board and the surrounding walls as well as the high luminance of the desk planes could cause visual discomfort and reduce learning productivity.

Table 5.2-7: Summary of luminance ratios along the viewing route in the classroom.

Time		Task-to-immediate surround	Task-to-far-surround background
Summer solstice	9:00 a.m.	1: 1	1: 6.9
	12:00 p.m.	1: 1.1	1: 2.6
	15:00 p.m.	1: 0.9	1: 1.4
Equinox	9:00 a.m.	1: 1	1: 4.9
	12:00 p.m.	1: 0.9	1: 1.8
	15:00 p.m.	1: 2	1: 2.5
Winter solstice	9:00 a.m.	1: 1	1: 4.2
	12:00 p.m.	1: 1.3	1: 3.3
	15:00 p.m.	1: 2.9	1: 3.6

- Summary of school E's daylighting performance

The daylight analysis of the four classrooms identifies several existing daylighting issues in the school, which are due chiefly to the building orientation. At the same time, it also reveals the gaps between the intention of the daylighting strategies employed, such as the 'light wells', and the actual overall daylighting performance. Moreover, the previous daylight analysis proves the importance of the opportunity that architects have to evaluate the likely daylight performance of their proposals and to modify them accordingly.

Classroom A, which has the worst orientation among the four selected classrooms, i.e. west, achieves the best performance in terms of daylighting sufficiency and even daylighting distribution. Although the western orientation increases the possibility of glare and visual discomfort in the afternoon periods, the three single-sided windows successfully provide the demanded useful daylight illuminances on the working plane in classroom A to support general teaching activities. Based on the DA and UDI analysis, it can be inferred that the daylighting strategies employed for the western classrooms, i.e. minimum three single-sided windows, can ensure an adequate daylighting environment, even though the internal blinds are always necessary, particularly during the afternoon. Further external shading devices, such as vertical shading on the western elevation, could be provided for future improvement.

For classroom B, two southern windows and a western window can only ensure the required daylighting environment on half of the working plane, which means that daylighting sufficiency cannot be completely achieved by the current glazing design (refer to the false colour map of DA in Table 0-11). However, the values of UDI-e occur up to nearly 40% in the vicinity of the southern windows, indicating the relatively high frequency of excessive daylight in the southern classrooms which can easily cause visual discomfort or an overheating problem. It can be found that the design of no more than two windows on the southern facade was applied for the southern classrooms generally. This strategy was designed by the architects to minimise the undesired solar radiation from the south, while it also decreases the daylighting adequacy in the southern classrooms, even though the secondary glazing was provided on the west.

For classrooms C and D which orient towards the north, neither of them achieves sufficient daylight based on the UDI analysis. The values of UDI achieved in classrooms C and D indicate that larger daylight accesses are demanded for the northern classrooms, and that the daylighting benefits from the central atrium is, factually, very limited. The variation of the amount of windows installed for the northern classrooms may be as a result of the aesthetic considerations for facade design taken by the architects, but the evaluation results show that this consideration conflicts with the daylighting performance required.

5.3 Ventilation efficiency and thermal comfort

To reduce energy consumption, natural ventilation has been selected as the primary ventilation strategy for four of the five schools studied, apart from school E which chiefly relies on mechanical systems. As a building's thermal environment is directly linked with the efficiency of its ventilation system, the thermal performance of the schools selected is summarised together with the ventilation performance in this section.

To assess ventilation efficiency and thermal environment of the schools studied, several classrooms were selected as the representative objects for on-site measurement and computerised monitoring. For assessing ventilation performance, four parameters relating to indoor air quality (IAQ) and ventilation efficiency were calculated via the Excel spreadsheet – Optivent – to investigate whether or not the cooling loads of a classroom in summer can be achieved by cross ventilation. The factor of internal CO_2 concentration plays an essential role in determining air quality of schools in accordance with Becker et al. (2007) Jones and Kirby (2012). However, this factor was not monitored in

the case studies due to the limitation of measurement equipment, and this can be concerned as one of the limitations of this research project.

On the other hand, POE via BUS Occupant questionnaires and on-site temperature measurement was conducted to investigate thermal environment of the schools studied. Meanwhile, the thermal environment in use reflects how effectively the ventilation strategies work, particularly in summer. To assess thermal environment of the schools, the parameters of dry bulb temperature (T), relative humidity (RH) and the external temperature were measured during the occupied periods at the specified internal spaces via Tinytag data loggers. Data had been recorded on-site for three weeks in summer or mild seasons and for three weeks in heating seasons, in average.

5.3.1 School A

In accordance with the detailed analyses in Section 4.2.2, the minimum air flow rate for the provision of fresh air can be achieved in school A. However, the current ventilation strategies can hardly control the excessive internal heat gains, particularly in summer months, and hence the overheating problem. For more specific analyses, details can be found in Section 4.2.2.

5.3.2 School B

- Ventilation analysis

The same classroom used for daylighting analysis was adopted as the research object to evaluate the efficiency of the ventilation strategies employed. Different modes of natural ventilation were displayed together in the following illustration (see Figure 5.3-1).





Ventilation holes on the wall between the classroom and the adjacent toilet



The outside of the air intake units and the panel opening



Finned tube heaters and attenuators were installed within the air intake units



The southern side of the ventilation chimney with louvres installed

Figure 5.3-1: Diagram of ventilation strategies (source: SWA and Author).

In the summer months, the ventilated air from the west can enter the classroom either via the air intake units under the windows or from the timber panels installed above the air intake units. After the air is heated by the internal heat gains, it can be extracted out of the classroom from the ‘chimney’ on top of the adjacent toilet by stack ventilation. The ‘brick holes’ on the wall between the

classroom and the toilet allow air to be extracted from the classroom to the chimney. This mode of ventilation was specifically designed for the summer months when excessive heat gains need to be removed, as well for mild seasons.

For the winter months, the timber panels will not be opened, and the fresh air from the cold outside will be pre-heated in the air intake units and then delivered into the classroom. Filters and attenuators as well as finned tube heaters were installed within the air intake units (refer to Figure 5.3-2 for construction details). However, "*some of the heaters inside of the air intake units are broken and cannot work properly*" was reported by the site manager (Andrew, interview, 22 October 2012).

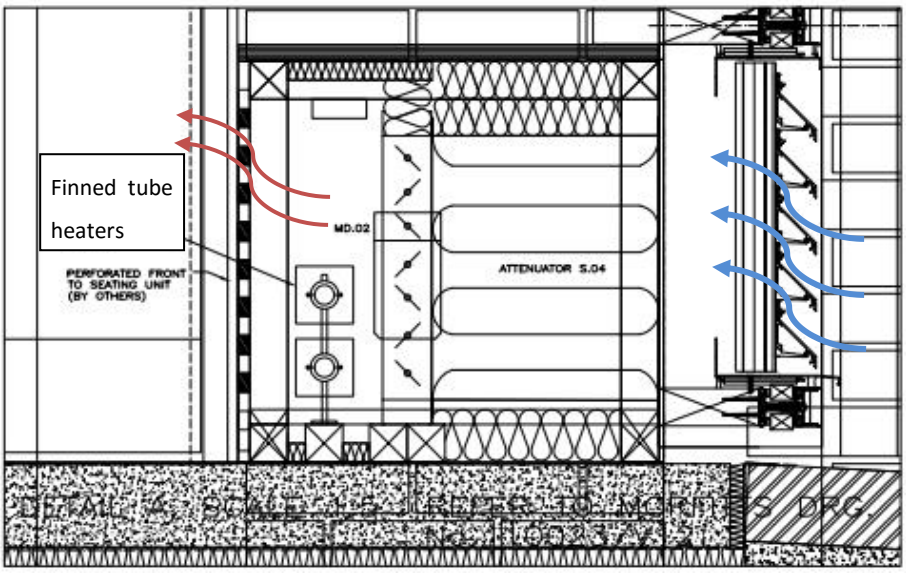


Figure 5.3-2: Details of the air intake units in classrooms (source: Max Fordham).

To evaluate the quality of the efficiency of the stack ventilation when excessive heat gains are required to be removed in summer, two scenarios of stack ventilation in the selected classrooms were assessed via Optivent - one is

purely reliant on the air intake units, and the other is only used to open the timber panels for ventilation. The dimensions of the tested classroom, the inlet and the outlet for different scenarios are displayed in Table 4.2-5 and Table 5.3-3, respectively.

For the calculation, a 'worst-case's scenario' (i.e. summer solstice at 12:00 p.m.) was chosen. Based on the location and orientation of the school, heat gains from the solar radiation via the northwest vertical glazing as well as the southeast horizontal glazing were calculated as 12.71 W/m^2 (refer to Table 4.2-6 for detailed information). The internal and external temperatures were set at 26°C and 24°C, respectively, and the scenario assumed that 27 children and one teacher occupied in the classroom doing light office work. Based on the values of heat gains from the occupants (i.e. in non-residential buildings) defined in the ASHRAE handbook (2009), the total internal heat gains from the occupants were 29 W/m^2. Heat gains from lighting and equipment were not considered in this simulation.

Table 5.3-1: The dimensions of the classroom for ventilation calculation - for only using the air intakes.

Zone dimensions	
Floor area (m^2)	61.5
Ceiling height (m)	3.45
Structural area inlet (m^2)	4.07
Structural area outlet (m^2)	2.66
Free open area inlet (%)	50
Free open area outlet (%)	50
Stack height (m)	5.4
Net free area inlet (m^2)	2
Net free area outlet (m^2)	1.3

Table 5.3-2: Heat gains of the classroom

Lighting	0	Total internal heat gains: 29 W/m^2
Occupants (W/m^2)	29	
Equipment	0	
Solar radiation- vertical surface (W/m^2)	157[1]	Solar heat gains from the northwest and southeast glazing: 12.71 W/m^2
Solar radiation- horizontal surface (W/m^2)	521	
Vertical glazing area (m^2)	6.2	
Horizontal glazing area (m^2)	3	
Transmittance factor- vertical glazing	0.6	
Shading proportion- Vertical glazing (%)	100[2]	
Roof U-values (W/m^{2}K)	0.18	
Total heat gains: 41.7 W/m^2		

Figure 5.3-3 shows the results of four parameters relating to IAQ and ventilation efficiency. The test results show that the air flow rate in the classroom achieves 29 l/s per person (i.e. 0.61 m^3/s for 21 adults) when the air intake units are half opened and the outlet is opened by 50% due to the louvre design. This value is sufficient to ensure the health of all the staff and pupils in the school. However, it is not sufficient to remove excessive heat gains from the occupants or solar radiation in summer, in accordance with the calculation results. Therefore, it can be inferred that *stack ventilation in the summer only via the air intake units and the outlets cannot provide the cooling loads required for the classroom.* This finding corresponds to the POE results regarding air temperature in summer; that in some classrooms the occupants suffer overheating problems. Although stack ventilation was provided, the size of the outlets is not large enough. This is a factor that should have been determined at the design stage; however, the external consultants

[1] The solar radiation scores were derived from Table 5.18 in the CIBSE Guide A (2006).

[2] The proportion of shading to the vertical glazing can be seen in the shading analysis where the northwest glazing can be fully shaded by the building itself at the summer solstice at noon.

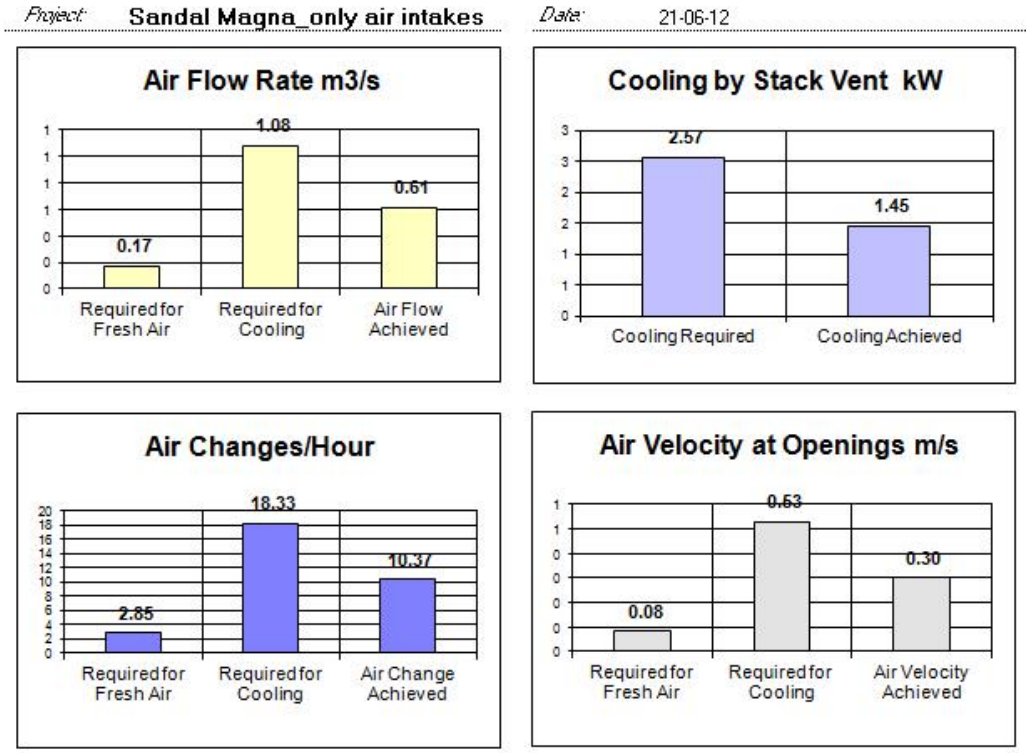


Figure 5.3-3: Ventilation results for the classroom - only using the air intake units (source: Optivent).

Table 5.3-3: The dimensions of the classroom for ventilation calculation - for only opening the panels.

Zone dimensions	
Floor area (m^2)	61.5
Ceiling height (m)	3.45
Structural area inlet (m^2)	4.65
Structural area outlet (m^2)	2.66
Free open area inlet (%)	90
Free open area outlet (%)	50
Stack height (m)	4.5
Net free area inlet (m^2)	4.1
Net free area outlet (m^2)	1.3

The ventilation results for the second scenario – to only open the panel as air inlets – are shown in Figure 5.3-4. Similar to the previous scenario, although

the ventilation rates achieve 30 l/s per person, this is still too low for the stack effect to remove the internal heat gains by the stack effect.

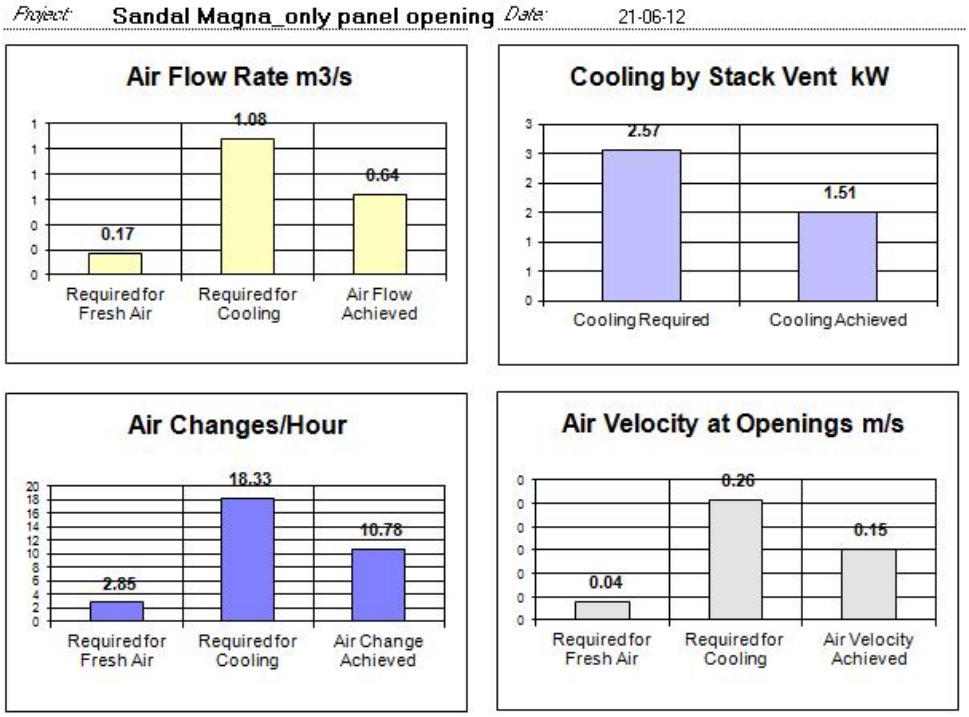


Figure 5.3-4: Ventilation results for the classroom - only opening the panels (source: Optivent).

For the winter months, it was proposed that the supply of fresh air for classrooms would be achieved via the air intake units. However, the issue of cool air draught was emphasised by the majority of the school staff based on the POE feedback for air quality in winter. As per the design of the ventilation towers (i.e. chimneys), the outlets were designed to face one direction, i.e. southeast. The prevailing winds in winter chiefly come from the west and the southeast. *Consequently, cold air from the southeast in winter can be pushed into chimneys under pressure, when the external air velocity reaches certain speeds, so that down draught could affect classrooms in the winter months.* This could be simply addressed by locating the air outlets on top of the chimneys and facing in different directions, such as the transformation shown

in the following sketch (see Figure 5.3-5).

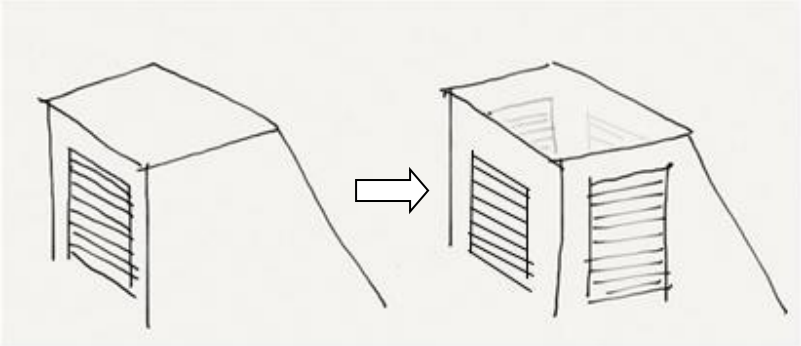


Figure 5.3-5: Different design for the air outlets on top of the chimney (source: Author).

- Thermal performance

To investigate whether thermal comfort is fully achieved in the school, two spaces in different locations of the school were selected as monitoring targets; a representative classroom in the northern block and a staff room in the southern block. Locations of the monitoring spaces are shown in Figure 5.3-6.



Figure 5.3-6: Locations of the monitored spaces for thermal analysis (source: SWA).

- Thermal performance in the summer months

Table 5.3-4 shows the summary of the thermal comfort results of the specified

spaces for a two-week period in the summer months, i.e. between 2 July 2013 and 15 July 2013. In this period when the selected spaces were occupied, the highest indoor temperature reached during the monitoring period was **29.8°C** in the staff room, indicating that the school staff who usually occupy this room could suffer some thermal discomfort in summer or during the free-running season due to high temperatures inside the room.

Table 5.3-4: Summary of the on-site measurement results for a two-week occupied period in the summer months.

Room	T_{min} [°C]	T_{max} [°C]	T_{ave} [°C]
Classroom	19.5	26	23.3
Staff room	22.5	**29.8**	25.3

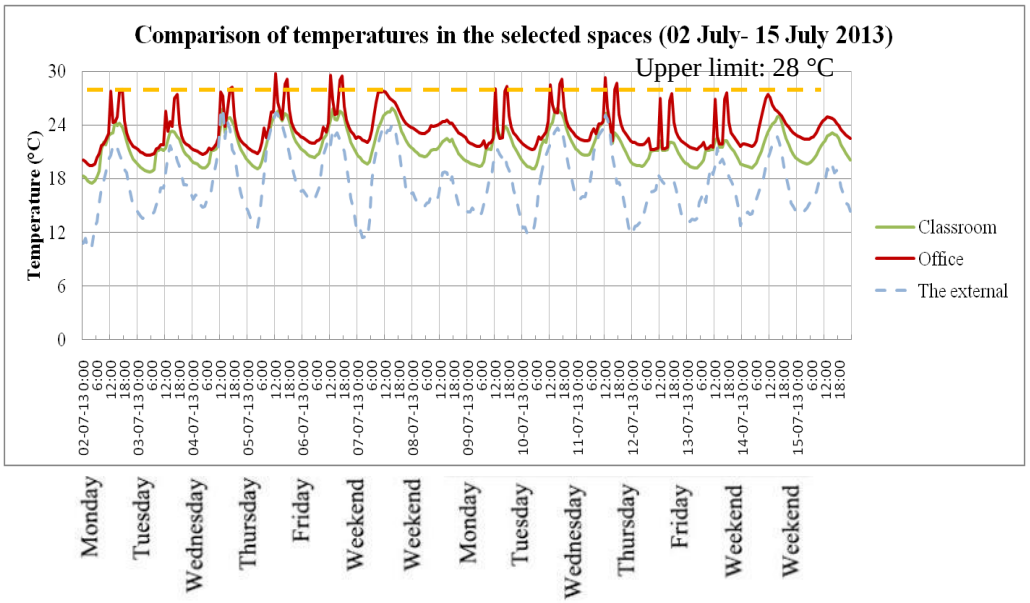


Figure 5.3-7: Temperature recorded in the monitored spaces over two weeks in the summer season (source: Author).

Referring to the above graph, the indoor temperature of the staff room is generally higher than the simultaneously occurring temperature of the

classroom in the monitoring period, where warmth appears to be caused by the direct solar radiation from the south-facing glazing in the staff room when no shading protection is provided. The indoor temperature of the southern staff room exceeds the upper limit of the comfort zone for the summer months (i.e. 26°C) almost every working day in the afternoon. In accordance with the previous shading analysis (see Table 0-1) and the glazing design in the staff room (see Figure 5.3-8), the southern elevation of the school is exposed to the direct solar radiation almost the whole year round, and there relatively large glazing was installed for daylighting purposes. In addition, the window opening appears not to be large enough for the provision of sufficient fresh air and to remove excessive internal heat gains from the occupants and the solar radiation. Lack of provision of any effective ventilation strategy is another reason for the overheating problem in the staff room. The above finding matches the POE feedback regarding thermal comfort in the school.



Figure 5.3-8: The glazing design for the southern staff room (source: Author).

- Thermal performance in the heating season

Heating is normally provided in the school when the external temperature falls below 16°C. For the thermal performance of the school in the heating season,

Table 5.3-5 shows the summary of the on-site measurement of the selected spaces between 8 October and 21 October 2012. In this two-week period, the temperatures found in the school vary with the warmest between 24.4°C (i.e. the classroom) and 25.7°C (i.e. the staff room) and the coolest being 17.1°C and 17.9°C for the classroom and the staff room, respectively. The average RH is generally 40%, but the maximum RH in the staff room achieves 99%.

Table 5.3-5: Summary of the on-site measurement results for a two-week occupied period in the heating season.

Room	T_{min} [°C]	T_{max} [°C]	T_{ave} [°C]	RH_{min} [%]	RH_{max} [%]	RH_{ave} [%]
Classroom	17.1	24.4	22.4	30.1	88.1	47
Staff room	17.9	25.7	22.4	35.3	99	52.7

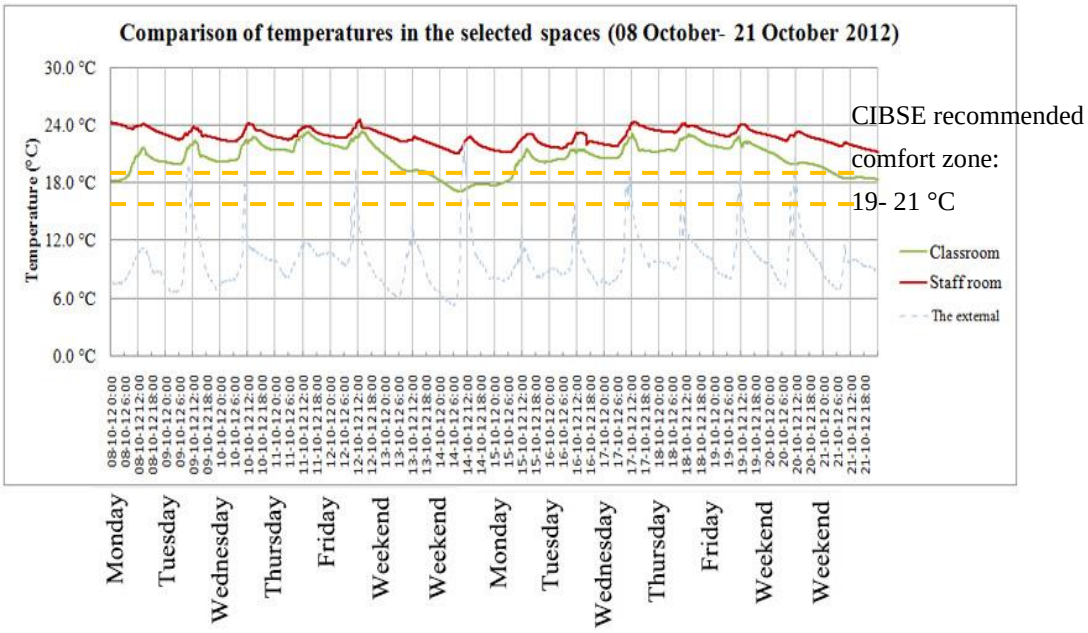


Figure 5.3-9: Temperature recorded in the monitored spaces over two weeks in the heating season (source: Author).

According to Figure 5.3-9, which displays a continuous two-week plot of temperatures recorded in the monitored rooms and the outside environment, it

can be seen that temperatures of the monitored spaces are generally above 19°C, indicating that it rarely gets cold in the monitored spaces when the heating is on. However, the occupant feedback regarding thermal comfort in winter reveals the issue of the classrooms being too cold, so it can be assumed that the above on-site measurement results do not fully reflect the thermal environment of the school in winter, as the external temperature at the time of the on-site monitoring did not fall below 6°C. Reading from the graph, temperatures recorded for the staff room are still higher than the simultaneous temperatures of the classroom, and are generally greater than the preferred upper limit of the comfortable temperature for winter seasons (i.e. greater than 21°C). This implies that thermal comfort can be achieved in the staff room as well as the classroom in most occupied hours. Nevertheless, heating could be excessively provided so that the issues of the 'winter-overheating' and less energy efficiency appear to be present due to the design of the staff room.

- Efficiency of the heating system

In the heating season, heating in the school is provided via the under-floor heating system and controlled by the BMS. Hot water for heating is provided by one ground-source heat pump powered by electricity. According to the schedule set out in the BMS, the heating system starts to work at 5:00 a.m. and stops providing heating during the lunch break at 12:00 p.m.

Figure 5.3-10 illustrates the temperature dynamics in the classroom as well as the staff room on the Monday of the second monitored week (15 October 2012). After a weekend over which heating was not provided, the initial temperature of the classroom and the staff room was above 20°C before the provision of heating. Over the period of four hours between 5:00 a.m. (the starting time of

heating) and 9:00 a.m. (the start of classes), the increase of the indoor temperature was approximately 3°C only. Due to the increase of internal heat gains from the occupants from 9:00 a.m., the indoor temperature of the classroom and the staff room reached 23°C and 25°C during the lunch break at 12:00 p.m., respectively. After the provision of heating ceased after noon, the indoor temperature tended to decrease from between 23°C and 25°C at noon to between 21°C and 24.5°C by the end of the school day (i.e. 15:30 p.m.). After the occupants left the school, the indoor temperature stayed above 20°C until the next time the heating started again, on Tuesday morning (16 October 2012).

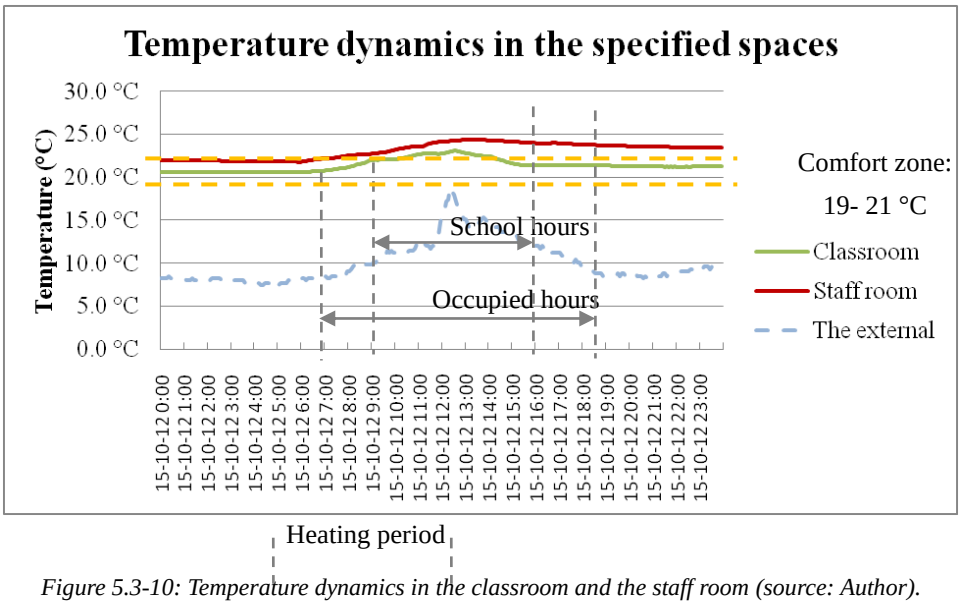


Figure 5.3-10: Temperature dynamics in the classroom and the staff room (source: Author).

Based on the above analysis, it can be inferred that the under-floor heating system in the school has a slow response to changes in conditions that may lead to less energy efficiency. The site manager also pointed out this issue during the interview. He expressed that the responding time for the under-floor heating system powered by the ground source heat pump took nearly three hours to achieve the desired temperature in winter which can cause high energy bill. Nevertheless, the initial temperature in the spaces after the weekend and the

slow speed of the decline in the indoor temperature prove that the thermal mass of the school performs at a very satisfactory level, as do as the insulation materials applied.

- Summary of ventilation efficiency and thermal performance

The ventilation and thermal analysis identifies the limitations of the current strategies employed for natural ventilation and thermal comfort. For the northern classrooms, natural ventilation is principally implemented by the stack effect via the air intake units, the panel openings, and the chimney outlets. Although the required ventilation rate for the supply of fresh air can be achieved, the air inlets and outlets are not large enough to remove excessive heat gains from the occupants and solar radiation in summer. In winter, the existence of cold draughty conditions reported by the occupants also proves the limitation of the chimney design. On the other hand, thermal comfort can be generally achieved in the northern classrooms based on the on-site monitoring results. Nevertheless, it was pointed out that some classrooms were cold in winter, and this could be caused by the cold draught from the chimneys.

For the staff room located in the southern block, the assessment indicates that both the ventilation and thermal performance are poor based on the current design. No specific ventilation strategy was provided for the southern block so that single-sided ventilation can only happen during periods when the window or the door is open. Besides this, there is no shading protection provided for the south-facing window and the glazing door; therefore, the internal heat gains from direct solar radiation from the southeast can lead to a very stuffy and overheated environment in the south block. The staff feedback regarding the temperature in summer also confirms the thermal discomfort in the school.

Although the school design has obvious disadvantages in terms of ventilation efficiency and thermal comfort, it is noteworthy, through the exposing of bricks inside of the school, that the thermal mass provides a good insulation for the school building and slows down the speed of heat loss to a large extent.

5.3.3 School C

To analyse the ventilation performance of school C, three classrooms were adopted as the research objects to evaluate the efficiency of the ventilation strategies employed - classroom 1 (i.e. northern classroom on the ground floor), classroom 2 (i.e. northern classroom on the first floor) and classroom 3 (i.e. southern classroom on the ground floor) (see Figure 5.3-11). Different modes of natural ventilation in different seasons are displayed in the following illustrations (see Figure 5.3-12 and Figure 5.3-13).

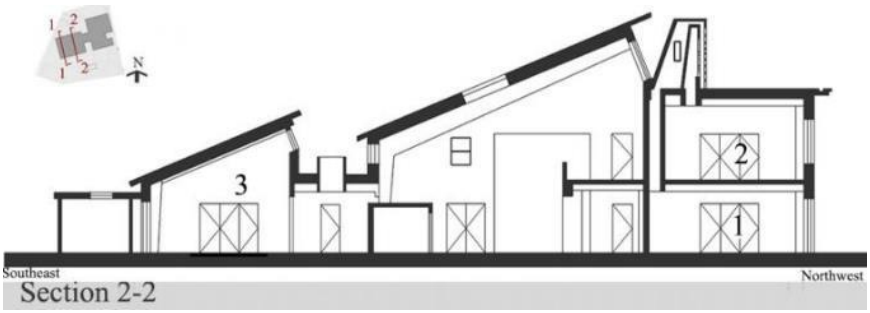


Figure 5.3-11: Locations of the selected classrooms for ventilation analysis (source: Architype).

- Ventilation analysis

In the spring and the autumn, prevailing winds chiefly from the southwest and the northwest are admitted into the selected classrooms through the lower window openings placed on the south-eastern and the north-western façades and can be extracted via the upper window openings (see Figure 5.3-12). Single-sided ventilation is the chief mode for the spring months.

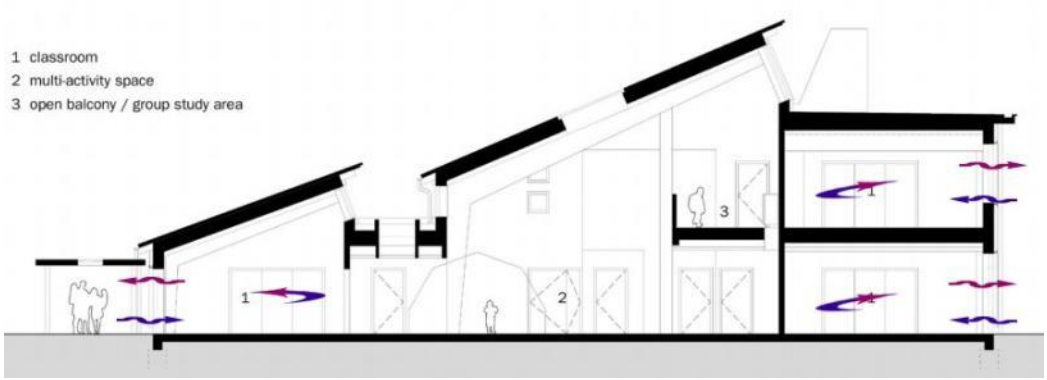


Figure 5.3-12: Single-sided ventilation in the school in the spring and the autumn (source: Architype).

In the summer, the prevailing winds come from the southwest. Cross-stack ventilation can be implemented via the window openings on the north-western façade and the chimney vents in the northern classrooms (see Figure 5.3-15), or via the window openings and doors on the south-eastern facade and the skylights facing the northwest in the southern classrooms (see Figure 5.3-16). Additionally, the stack's outlets which are only oriented to the northwest could cause a risk of downdraughting if winds do occasionally come from a northerly direction in accordance with the prevailing winds in summer in Wolverhampton (see Figure 5.3-14)

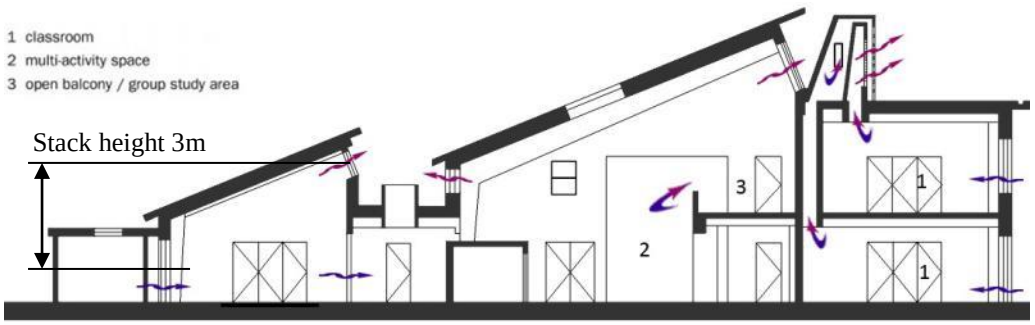


Figure 5.3-13: Cross-stack ventilation in the school in the summer (source: Architype).

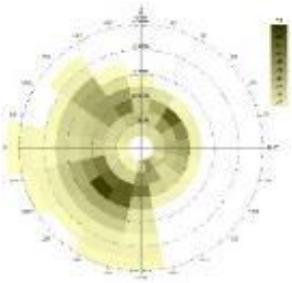


Figure 5.3-14: Summer's wind rose for Wolverhampton (source: Ecotect).



Figure 5.3-15: Ventilation inlets and outlets for the northern classrooms on the first floor (source: Author).



Figure 5.3-16: Ventilation inlets and outlets for the southern classrooms on the ground floor (source: Author).

The 'stack' heights of the three classrooms are shown in Figure 5.3-13 and Figure 5.3-17. Based on the setting in the BMS system, when the indoor temperature exceeds 26°C (i.e. the upper limit of thermal comfort zone in summer according to the CIBSE Guide A 2006), the BNS is supposed to open the windows automatically so that stack ventilation can exhaust warm air out

and bring fresh air in. When the internal temperature falls below 26°C, the occupants also have personal controls to open/close the window openings in case thermal adjustment is required.

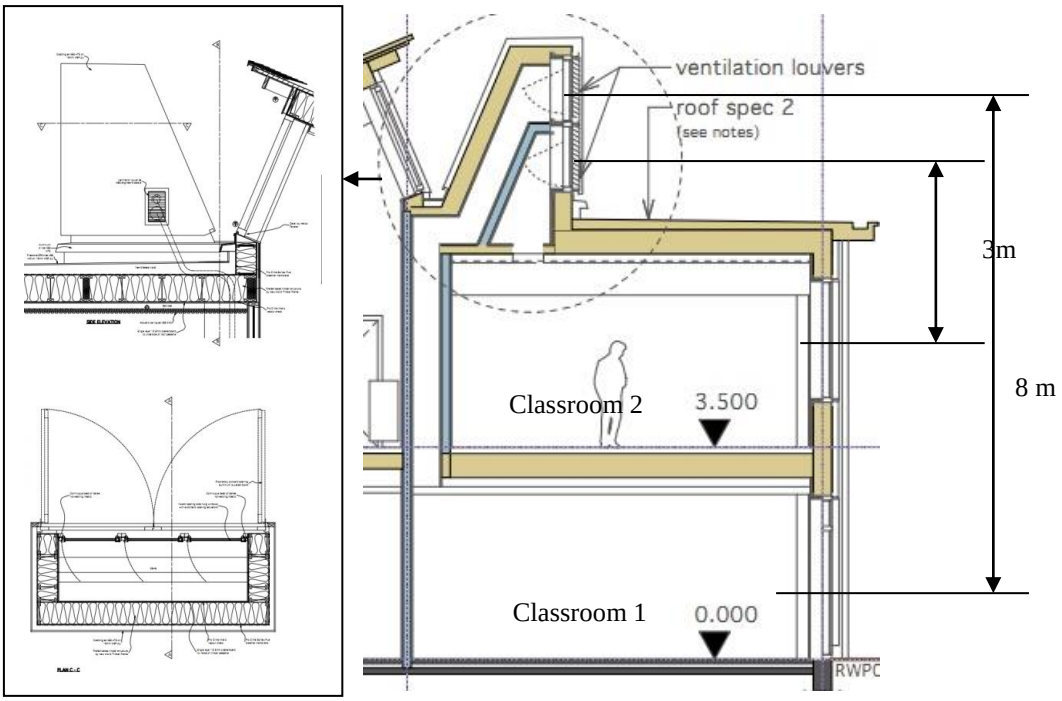


Figure 5.3-17: Stack heights for different classrooms, with the chimney's constructional details (source: Architype).

In the winter months when the occupants only have the requirement of the supply of fresh air, the ventilation louvres installed on the external elevations were designed to permit single-sided ventilation that can allow fresh air in and extract waste air out. Details of the ventilation louvres can be found in Figure 5.3-18.



Figure 5.3-18: The external and the internal appearance of the ventilation louvres (source: Author).

To evaluate the quality of ventilated air and the efficiency of the cross ventilation when cooling was required in summer, a simple spreadsheet tool (Optivent) was used to calculate the achieved ventilation rates, the air changes/hour, and the cooling loads achieved by the stack vent in the selected classrooms driven by heat gains from the occupants and solar gains. The dimensions of the tested classrooms, the inlets and the outlets are displayed in Table 5.3-6.

For the calculation, a 'worst case' (i.e. summer solstice at 12:00 p.m.) was chosen for the purpose of calculating solar radiation gains. Based on the location and orientation of the school, heat gains from the solar radiation via the southeast vertical glazing and the northwest glazing were calculated as 0.05 W/m^2 (refer to Table 5.3-7 and Table 4.2-6 for detailed information). The internal and external temperatures were set at 26°C and 24°C, respectively, and the scenario assumed that 25 children and two teachers doing light office work occupied the classroom. Based on the values of heat gains from the occupants defined in the ASHRAE handbook (2009), the total internal heat gains from the occupants were 26.3 W/m^2 and 29.8 W/m^2 in the northern classrooms and the

southern classroom, respectively. Heat gains from lighting and equipment were not considered in this simulation.

Table 5.3-6: The dimensions of two northern classrooms (i.e. classroom 1 and 2) and a southern classroom (i.e. classroom 3) for ventilation calculation.

Classroom dimensions	Classroom 1	Classroom 2	Classroom 3
Floor area (m^2)	60	68	68
Ceiling height (m)	3.5	3	3
Structural area inlet (m^2)	7.6	7	6.48
Structural area outlet (m^2)	4	3.36	3.36
Free open area inlet (%)	50	50	50
Free open area outlet (%)	50[3]	50	50
Stack height (m)	3	3	8
Net free area inlet (m^2)	3.8	3.5	3.24
Net free area outlet (m^2)	2	1.68	1.68

Table 5.3-7: Heat gains of classrooms 1 and 2.

<table>
<tr><td>Lighting, equipment</td><td>0</td><td rowspan="2">Total internal heat gains: 26.25 W/m^2</td></tr>
<tr><td>Occupants (W/m^2)</td><td>26.25</td></tr>
<tr><td>Solar radiation - vertical surface (W/m^2)</td><td>138[4]</td><td rowspan="6">Solar heat gains from the southeast glazing: 0W/m^2</td></tr>
<tr><td>Vertical glazing area (m^2)</td><td>12.75</td></tr>
<tr><td>Horizontal glazing area (m^2)</td><td>0</td></tr>
<tr><td>Transmittance factor - vertical glazing</td><td>0.55</td></tr>
<tr><td>Shading proportion - vertical glazing (%)</td><td>100</td></tr>
<tr><td>Roof U-values (W/m^{2}K)</td><td>0.1</td></tr>
<tr><td colspan="3">Total heat gains: 26.25 W/m^2</td></tr>
</table>

[3] The free open area for the outlets was determined by the areas of the louvres to the total open areas of the stack outlets.

[4] The solar radiation scores were derived from Table 5.18 in the CIBSE Guide A (2006).

Table 5.3-8: Heat gains of classroom 3.

Lighting, equipment	0	Total internal heat gains: 29.75 W/m^2
Occupants (W/m^2)	29.75	
Solar radiation - vertical surface (W/m^2)	265	Solar heat gains from the southeast glazing: 0.05 W/m^2 （from indirect radiation gains)
Vertical glazing area (m^2)	12.34	
Horizontal glazing area (m^2)	0	
Transmittance factor - vertical glazing	0.55	
Shading proportion - vertical glazing (%)	100	
Roof U-values (W/m^{2}K)	0.1	
Total heat gains: 29.8 W/m^2		

Figure 4.2-15, Figure 5.3-20 and Figure 5.3-21 show the results of IAQ and ventilation efficiency for classroom 3, classroom 1, and classroom 2, respectively. The test results show that the air flow rate in classroom 3 (southern classroom) achieves 35.7 l/s per person (i.e. 0.78 m^3/s for 21 adults), when the effective free area is assumed to be 50% of the structural opening area. This value is sufficient to ensure the minimum level of fresh air supply and also sufficient to remove excessive heat gains from the occupants as well as solar radiation in summer. Thus, in this scenarios, the cross-stack ventilation just works effectively in the southern classrooms in terms of providing the necessary cooling effect. Nevertheless, when the external air temperature was higher than 24°C, e.g. 25°C, the occupants in the southern classroom may have a big risk of being overheated.

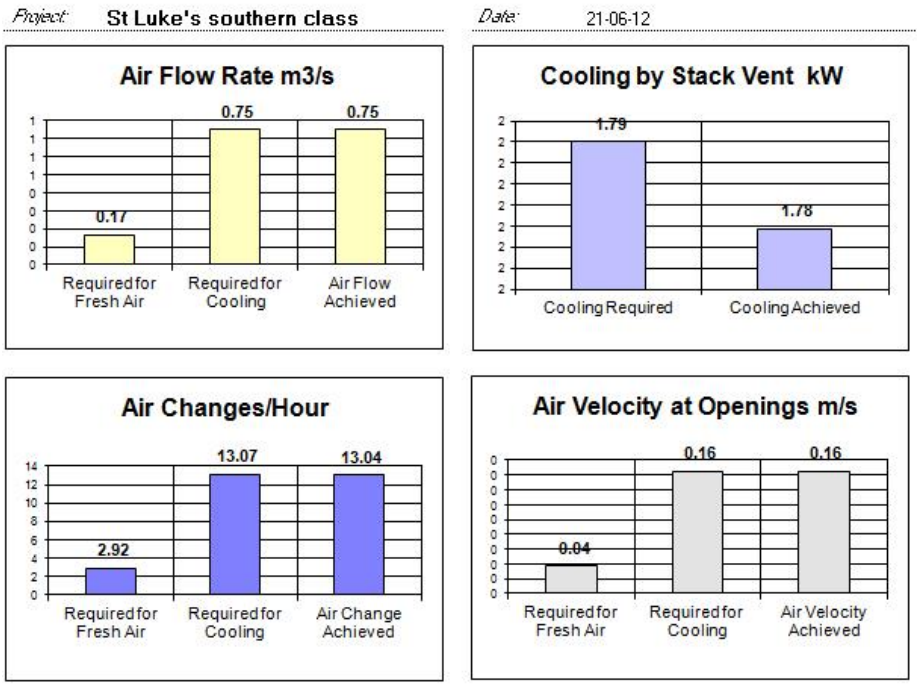


Figure 5.3-19: Ventilation results for classroom 3 in summer- assumption information can be found in Table 5.3-9 and Table 5.3-10 (source: Optivent).

For the northern classrooms, the air flow rates in classroom 1 (on the ground floor) and classroom 2 (on the first floor) reach 47.6 l/s per person (i.e. 1 m^3/s for 21 adults) and 29.5 l/s per person (i.e. 0.62 m^3/s for 21 adults), respectively, when the inlet (i.e. window openings on the northwest elevation) and the outlet (i.e. northwest-facing chimney vents) are assumed to have a free area of 50% of the structural opening area due to the louvre design. For classroom 1 on the ground floor, the air flow rate achieved is sufficient to remove excessive heat gains from the occupants in summer. However, it seems that cross-stack ventilation via the existing inlets and outlets cannot provide the cooling loads required for classroom 2 on the first floor, according to the air flow rate achieved, i.e. 29.5 l/s per person (see Figure 5.3-21). As the internal heat gains assumed for classroom 1 and classroom 2 are similar, as well as the sizes of the inlets and the outlets adopted, the different air flow rates achieved are due largely to the different stack heights, i.e. three metres for classroom 2 and eight

metres for classroom 1. Therefore, it can be assumed that to improve the ventilation efficiency in classroom 2, enlarging the size of the outlet for classroom 2 can be helpful.

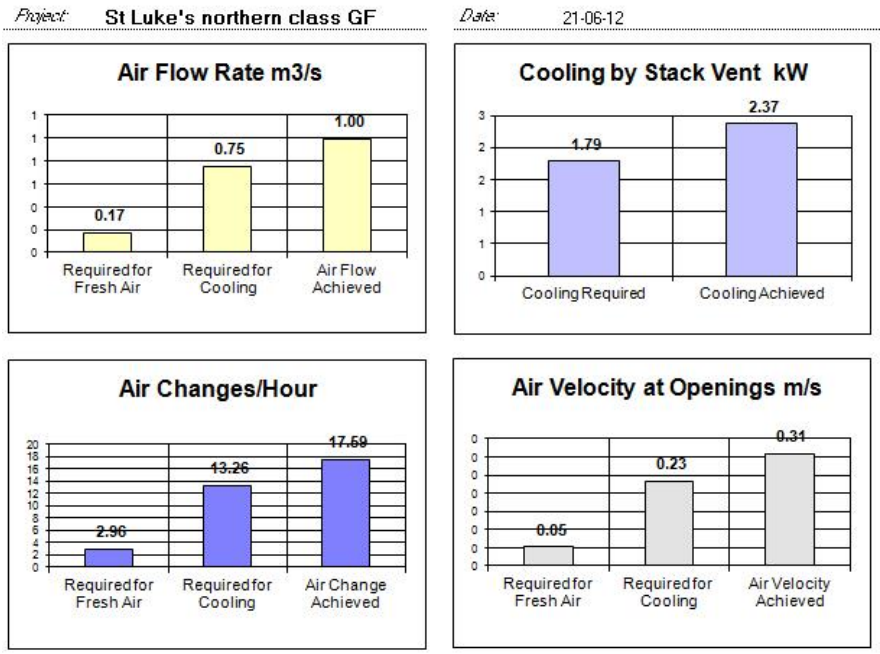


Figure 5.3-20: Ventilation results for classroom 1 in summer- detailed assumption information can be found in Table 5.3-11 and Table 5.3-12 (source: Optivent).

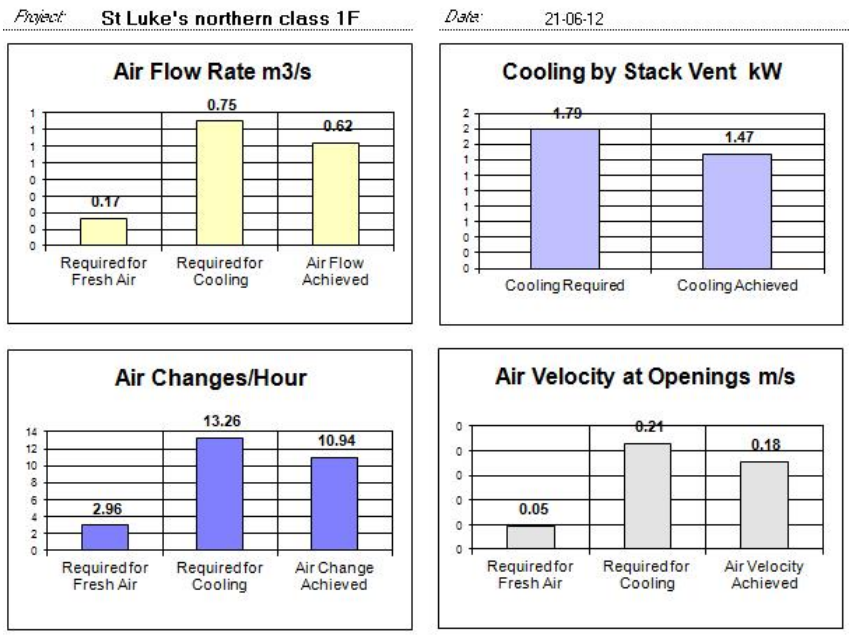


Figure 5.3-21: Ventilation results for classroom 2 in summer- detailed assumption information can be found in Table 5.3-13 and Table 5.3-14 (source: Optivent).

According to the above ventilation analysis, it can be inferred that, outside of the heating season, the overheating problem could *potentially* exist in the northern classrooms on the first floor and the southern classroom when the external temperature is relatively high (i.e. greater than 25°C and the temperature difference between the inside and the outside is less than 2 °C). However, referring to the POE results regarding the variable of 'Temperature in summer' in the school, the school occupants did not give any negative feedback. There could be several reasons for the differences between the Optivent prediction and the occupant feedback. Additionally, the Optivent assumes a scenario of a 'light-weighting' building which does not account for thermal mass; therefore, in practice, mass effects could be a contributing reason.

On the other hand, in accordance with BB 101 (2006), if the overheating hours in the occupied hours in a year are less than 120 hours, thermal discomfort due to high temperature inside is acceptable. For this reason, it is necessary to further investigate whether or not the overheating problem does exist in the school in practice and how often it occurs in a year. To answer these questions, on-site monitoring and TAS simulation were conducted in this study, and the relevant results are explained in the following section.

On the other hand, the occupants' behaviours such as changing clothes, moving to window openings and opening windows can change the occupants' thermal comfort level, referred to as "adaptive thermal comfort" (Brager and de Dear 1998; Nicol and Humphreys 2002). Leaman and Bordass (1999) also have demonstrated that the occupants can show more 'forgiveness' of buildings when they have more access to building controls. This corresponds to the POE results regarding 'Personal controls over ventilation' where over 80% of the

school staff were pleased that they were able to open/close window openings in the school, so they could overlook shortcomings in the school's thermal environment more readily (Brager and de Dear 1998).

Besides the above findings regarding the ventilation performance of the school, there is one more thing that should be noted. According to the POE results in terms of the air quality in winter, the issue of "*still air*" and "*poor ventilation*" in the office spaces was pointed out by most of the school staff (refer to Section 4.3.2). This is due largely to the glazing design for most of the cellular offices in the school, as there are very small glazed areas installed in the office spaces and some offices do not even have openings facing the outside. As the building fabric is prefabricated with high insulation, the architects planned for fewer openings on the external elevations in order to maintain the insulation of the building fabric.

- Thermal performance

The same classrooms selected for the ventilation analysis were chosen as the monitored targets for the thermal analysis.

- Thermal performance in the mild season

Table 5.3-15 shows the summary of the on-site measurements (temperature and RH) results of the specified spaces for a three-week period between September and October 2012, i.e. between 24 September 2012 and 12 October 2012. According to the on-site measurement, the highest temperature generally occurs around noon, and the coolest temperature is normally recorded in the morning, when the school is first occupied. The average RH of the monitored spaces is all above 40%.

Table 5.3-15: Summary of the on-site measurement results for a two-week occupied period in March 2012.

Room	T_{min} [°C]	T_{max} [°C]	T_{ave} [°C]	RH_{min} [%]	RH_{max} [%]	RH_{ave} [%]
Classroom 1 (GF, N)	19.0	23.3	21.8	37.5	72.5	55.9
Classroom 2 (1F, N)	19.9	23.5	22.3	35.9	71.6	54.8
Classroom 3 (GF, S)	19.8	24.3	22.2	39.6	74.8	58.7

Figure 5.3-22 displays a continuous three-week plot of temperatures recorded in all monitored spaces and the outside environment. It can be seen from the graph that the external temperature during the monitored period is on average between 10°C and 15°C, but the indoor temperature in the monitored spaces is generally between 20°C and 25°C which is located within a comfortable range for the occupants.

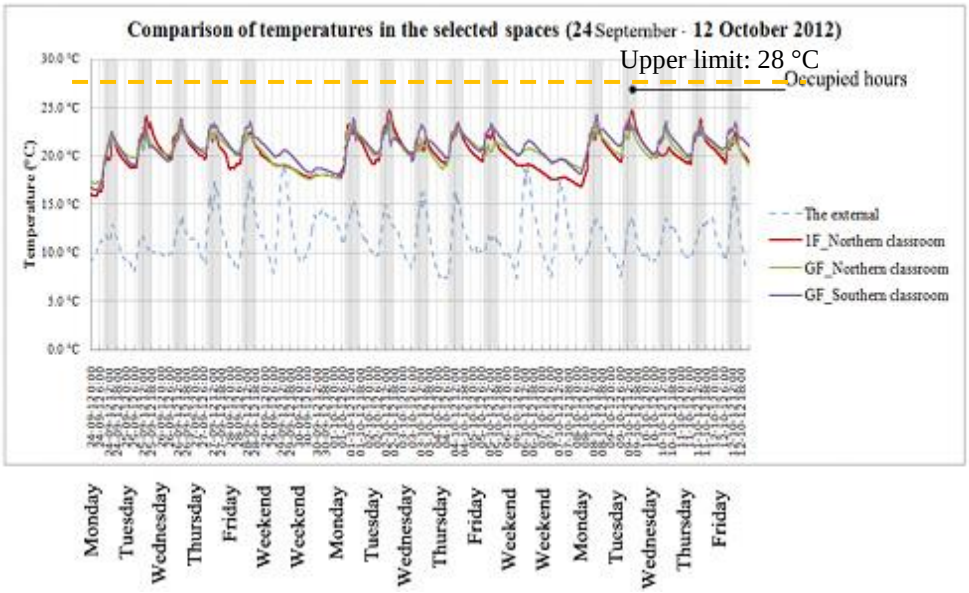


Figure 5.3-22: Temperatures recorded in the monitored spaces over three weeks in the free-running season (source: Author).

The temperature in the specified classrooms normally starts to increase after

the rooms have been occupied since 8:30 a.m., and reaches its peak between 12:00 p.m. and 13:00 p.m. As there was no heating provided in this period, the increase of the indoor temperature in the monitored spaces is due largely to the internal heat gains from the occupants, lighting, and the equipment in use. During the lunch break, the teaching staff usually opened windows in the classrooms, and the children left the classrooms and stayed in the central hub spaces. The indoor temperature in the monitored classrooms therefore starts to decrease after the lunch break, but is maintained at a comfortable level until the school is completely empty at 18:00 p.m. According to the recorded data, it can be inferred that thermal comfort in the classrooms can be achieved in September and October.

- Thermal performance in March

Following negotiation with the school, the author was permitted to carry out her on-site measurements during a two-week period in March (i.e. between 19 March and 1 April 2012). As the average daytime temperature of the second week in this period was generally above 22°C and the highest daytime external temperature was even higher than 25°C on the 28 March 2012 (refer to Figure 5.3-23), it could therefore be assumed that, in the second week of the monitoring period, a risk of overheating could occur in the monitored spaces. However, because the data were recorded in a 'non-typical' summer month, a further computerised simulation using Bentley's TAS program[5] was carried out in this study as supplementation to assess whether thermal comfort can be achieved in the monitored classrooms in the summer months.

[5] TAS simulator designed by Bentley is to simulate thermal performance of buildings.

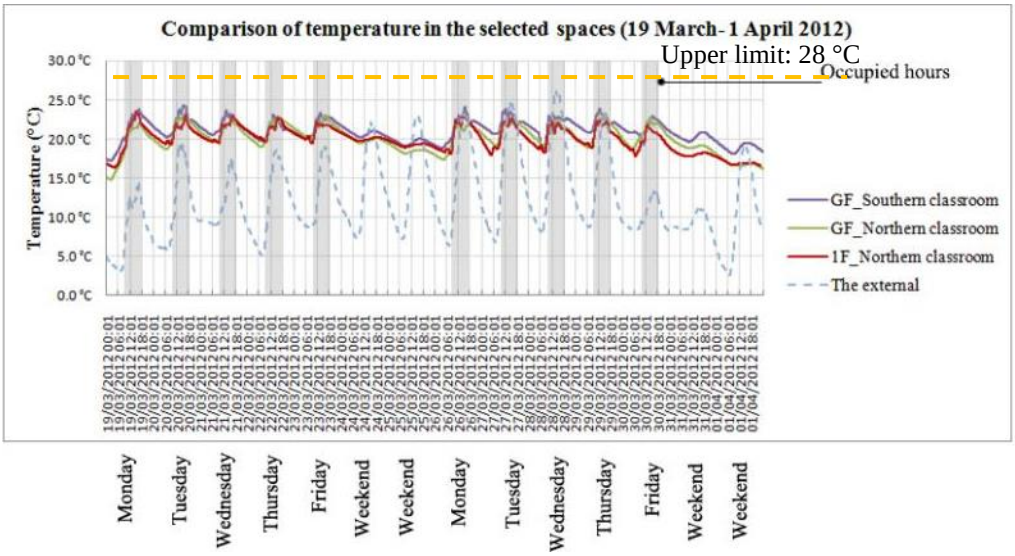


Figure 5.3-23: Temperature recorded in the monitored spaces over two weeks in March 2012 (source: Author).

Based on the temperature data recorded in the second week of the monitoring period (can be found in Figure 5.3-23), the external temperature during the school occupied hours between 26 March and 30 March 2012 were generally higher than 20°C; and hence it was assumed that a risk of overheating would appear in the monitored classrooms during the occupied hours, over the four-day period. Referring to the on-site measurement results, the temperatures in all the monitored classrooms during the occupied hours in these four days were between 20°C and 23.5°C, while natural ventilation was adopted, therefore implying that there was no overheating problem during this period.

To further evaluate whether the overheating problem exists in the school in the summer months, the TAS program computed the indoor dry bulb temperature of the previously-specified spaces, i.e. classroom 1 (northern classroom on the ground floor), classroom 2 (northern classroom on the first floor) and classroom 3 (southern classroom on the ground floor), outside of the heating season and during the occupied period of 9 a.m. and 4 p.m., Monday to Friday,

from 1 May to 30 September, using the CIBSE TSY weather data for Wolverhampton. For internal conditions, it was assumed that there are 25 children and two teachers carrying out light office work without lighting and equipment considerations. Windows and chimney vents were set to be opened when the indoor temperature exceeds 28°C, and all the apertures were set to be opened by 50%.

The number of hours when the internal temperature of the monitored spaces was above 28°C was calculated by TAS program, and the results are displayed in Figure 5.3-24 (Detailed information of the calculation can be found in Appendix). We can see that, for all the monitored classrooms during the simulating period, the number of hours in which the internal dry bulb temperature is greater than 28°C is less than 80, which is also less than the recommended level in accordance with BB 101, i.e. 120 hours. Additionally, none of the three classrooms' temperature exceeds 32°C. Thus, it can be inferred that thermal comfort can be achieved in the classrooms during the cooling season. Nevertheless, the data shown in Figure 5.3-24 indicate that the number of 'overheating' hours (i.e. greater than 28°C) in classroom 2 (northern classroom on the first floor) is nearly twice as much as that in classroom 1 (northern classroom on the ground floor). This corresponds to the assumption drawn from the Optivent prediction analysis that classroom 2 may run a higher risk of being overheated in comparison with the other classrooms.

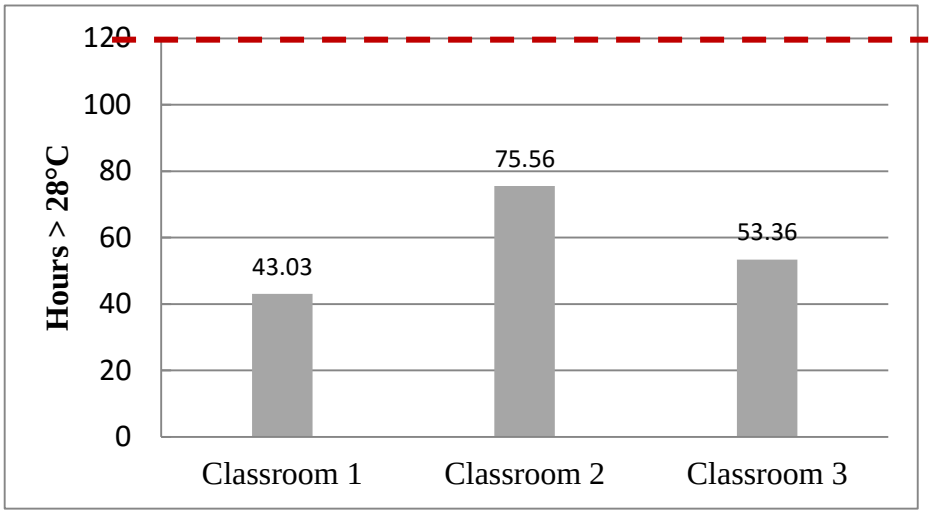


Figure 5.3-24: The number of hours when the internal temperature is above 28°C in the specified classrooms (source: Author).

- Summary of ventilation efficiency and thermal comfort

The ventilation and thermal analysis indicates that thermal comfort can be generally achieved in all the learning spaces in the school based on the current glazing design as well as on the natural ventilation strategies. The different modes of natural ventilation can provide sufficient air flow rate to supply fresh air for the school occupants, and, to a large extent, can also assure thermal comfort in the classrooms in the summer months, although air quality in classroom 2 (i.e. the northern classroom on the ground floor) may be an issue in the summer months.

Additionally, it is noteworthy that the issue of insufficient ventilation in the office spaces was revealed via the POE results; this was negatively affecting the productivity and health of the staff. Thus, further improvement to the air quality in the office spaces is required, such as by adding mechanical vents.

5.3.4 School D

- Ventilation analysis

Two modes of natural ventilation, i.e. single-sided ventilation via the upper and lower window openings, and cross-stack ventilation via the window openings and chimneys at the back of classrooms, were designed by the architects to supply fresh air for the occupants and to remove excessive heat gains from the occupants and solar radiation from the classrooms (Figure 5.3-25). Night-time cooling via the upper openings and the chimneys was also designed to ensure thermal comfort in the classrooms in summer.

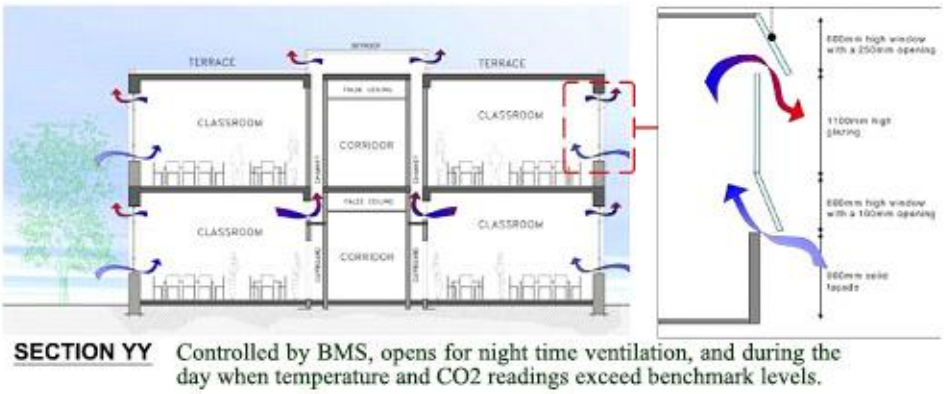


Figure 5.3-25: Natural ventilation strategies for classrooms (source: P&P).

Similar to the glazing design for classrooms analysed previously, the same ventilation strategies were applied for all the classrooms in terms of size of the air inlets and outlets and the height of chimneys, irrespective of the direction they are oriented to. However, the hypothesis is *that rooms with different orientations will have different levels of solar and wind exposure and hence should have different ventilation strategies.*

As mentioned above, Buro Happold made a series of theoretical predictions of

the school's ventilation and thermal performance in order to suggest proper ventilation and thermal strategies for the school. They computed thermal performance of two standard classrooms with different orientations in accordance with three different modes of natural ventilation:

- single-sided ventilation via the upper and lower window openings
- cross-stack ventilation via the window openings and the chimneys during the daytime only
- and cross-stack ventilation during the day, and at night.

According to their prediction analysis, Buro Happold proved that, theoretically, thermal comfort in both the north-facing and the south-facing classrooms in summer can be achieved via the cross-stack ventilation both during the daytime and at night, while the south-facing glazing should be solar controlled to avoid excessive solar heat gains in summer. However, based on the POE results regarding the air quality and thermal comfort in the school, many complaints were raised by the school users, relating to the "*poor ventilation*" and the overheating issue in classrooms. Thus, an Optivent prediction based on the current building configuration and ventilation strategies was conducted. A southern standard classroom on the ground floor was then selected as the simulated space. In the simulation, two scenarios - one is only single-sided ventilated, and the other is only cross-stack ventilated - were assessed in the simulation.

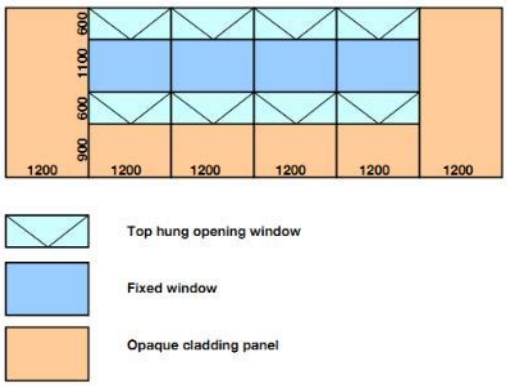


Figure 5.3-26： Glazing design and openable ventilation panes for standard classrooms in Minster School (source: Buro Happold)

- Case 1: Single-sided ventilation only for a southern classroom on the ground floor

Figure 5.3-27 shows the results of Optivent prediction regarding the air flow rates and ventilation efficacy achieved in a southern classroom on the ground floor by single-sided ventilation. When the bottom panes (air inlets) and the upper panes (air outlets) are both open at 90%, the air flow rate in the southern classroom achieves 22.4 l/s per person (i.e. 0.56 m^3/s for 30 children and one adult), when the effective free area is assumed to be 90% of the structural opening area. This value is sufficient to ensure the minimum level of fresh air supply (i.e. 8 l/s per person in accordance with BB 101), but is insufficient to remove excessive heat gains from the occupants as well as solar radiation in summer. Thus, in this scenarios, it can be inferred that the overheating problem could exist in the southern classrooms in summer if the classrooms are only single-sided ventilated

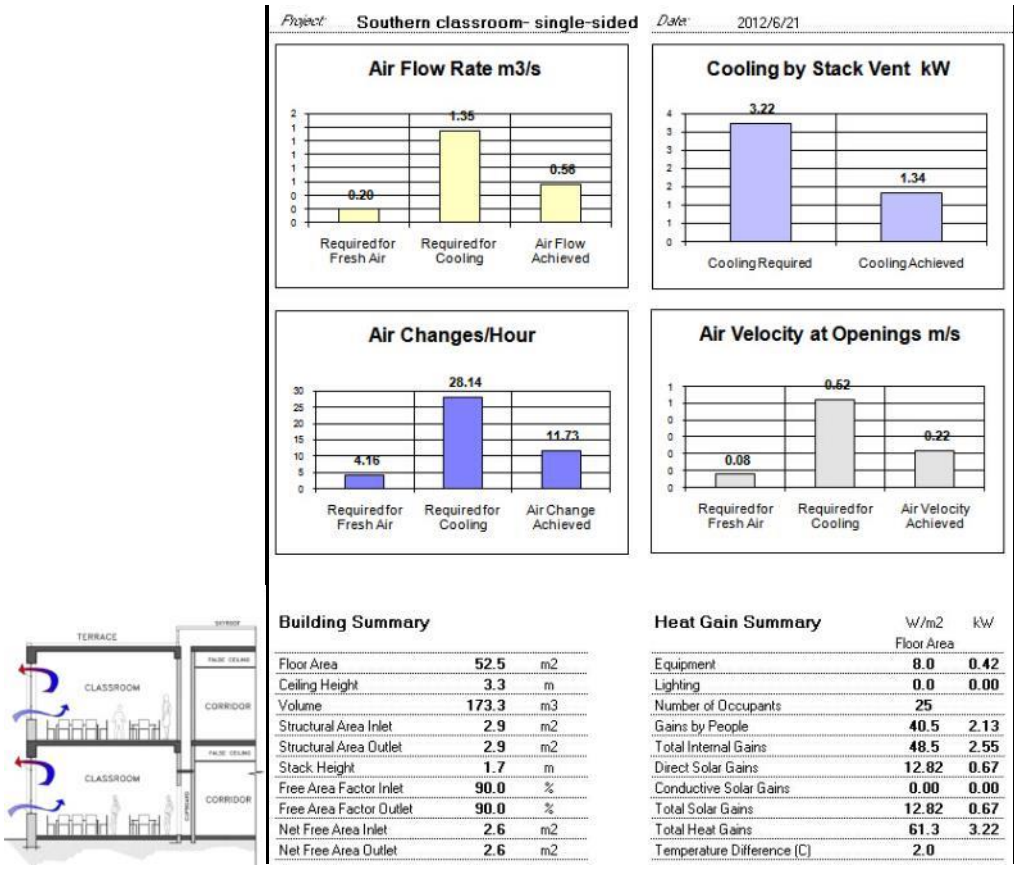


Figure 5.3-27: Optivent results- ventilation efficacy of single-sided ventilation for a southern classroom on the ground floor in summer (source: Optivent).

- Case 2: Cross-stack ventilation only for a southern classroom on the ground floor

Figure 5.3-28 shows the results of Optivent prediction regarding the air flow rates and ventilation efficacy achieved in a southern classroom on the ground floor by cross-stack ventilation only. When the bottom panes of the window (air inlets) and the chimney vent (air outlets) are both open, the air flow rate in the southern classroom achieves 29.2 l/s per person (i.e. 0.73 m^3/s for 30 children and one adult), when the effective free area is assumed to be 90% of the structural opening area. The value of the air flow rate achieved via cross-stack ventilation is higher than the air flow rate achieved via single-sided ventilation; however, it is still insufficient to remove excessive internal heat

gains from the occupants and equipment and the solar heat gains.



Figure 5.3-28: Optivent results- ventilation efficacy of cross-stack ventilation for a southern classroom on the ground floor in summer (source: Optivent).

According to the above Optivent perdition analysis, it can be inferred that, in summer, when the classroom is fully occupied, the required air flow rate to remove excessive heat gains cannot be achieved in the southern classrooms by simply using single-sided ventilation or cross-stack ventilation. This finding corresponds to the POE feedback regarding 'Ventilation in summer' that the issue of insufficient ventilation was raised by majority of the school staff. To use the mixed mode of natural ventilation, i.e. single-sided and cross-stack ventilation both work effectively based on the present effective opening (i.e. ventilation panes both open) may be able to achieve the required ventilation

rate to remove excessive heat gains. In addition, to enlarge the area of the chimney vents and the upper panes of the windows may have been able to resolve the issue of insufficient ventilation. However, as the top panes of the external windows are controlled by BMS that they open eventually when the internal CO_2 level also goes higher with the indoor temperature; hence, it can be inferred that the occupants in the southern classrooms may have a big risk of being overheated which matches the occupant feedback towards thermal comfort in the school.

On the other hand, the prevailing winds in Nottingham comes from the southwest, but it can be seen from Figure 5.3-29 that the main teaching blocks of Minster School which orient towards the southeast and the northwest also get a substantial wind flowing throughout a year. As the chimney vents only face a single direction (i.e. southeast or northwest) and they are inoperable hence always remaining open, the downdrafting problem may exist in some classrooms when the external air velocity exceeds certain levels.

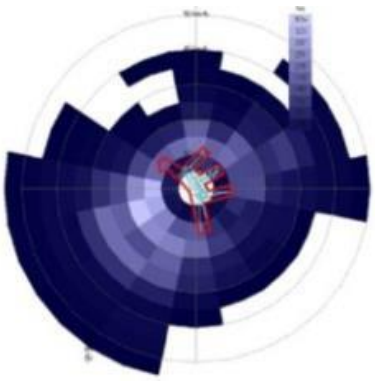


Figure 5.3-29: Wind rose of Nottingham (source: CIIBSE weather data 2005).

- Thermal performance

In accordance with the previous analysis of ventilation performance, the

findings indicate that thermal discomfort due to the inefficient ventilation can exist in the teaching/learning spaces. Hence, to investigate whether or not thermal comfort is achieved in the school, four spaces in different locations of the school were selected as monitoring targets when they were occupied; two standard classrooms on the ground floor in the middle 'finger', an east-facing staff room adjacent to the central 'heart space' on the first floor and a staff office in the western part of the school with no window directly facing the outside (see Figure 4.2-17).

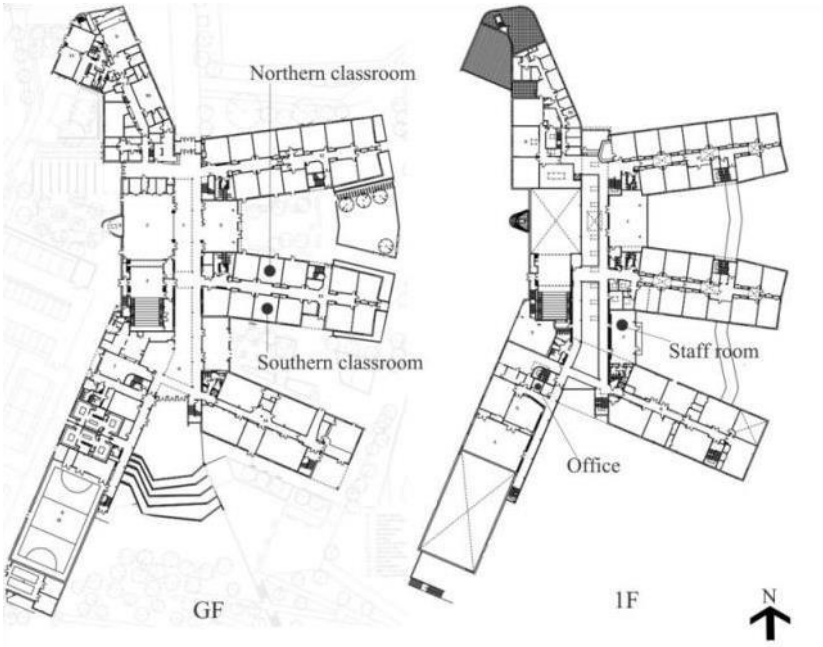


Figure 5.3-30: The locations of Tinytag data loggers in the specified spaces (source: P&P).

According to the design strategy applied, it was assumed that window panes in the selected classrooms and the staff room would be automatically opened when the indoor temperature exceeds 28°C and the CO_2 concentrate is above the recommended limits based on the design proposals. It was assumed that, for the selected office with no window openings, air conditioning would be used in July.

- Thermal performance in July

Table 5.3-16 shows the summary of the thermal comfort results of the specified spaces for a two-week period in July when the school was occupied, i.e. between 16 July 2012 and 29 July 2012.

Table 5.3-16: Summary of the on-site measurement results for a three-week occupied period in July 2012.

Room	T_{min} [°C]	T_{max} [°C]	T_{ave} [°C]	RH_{min} [%]	RH_{max} [%]	RH_{ave} [%]
Northern classroom	20.2	**28.2**	22	35.3	87.2	57.2
Southern classroom	19.1	**27.3**	21.7	33.9	97	56.3
Eastern staff room	21.2	**31.8**	**26.2**	24.6	87.5	44.9
Cellular office	19	**27.5**	25	29.4	86.1	46.6

Referring to the average temperature in the monitoring spaces when they were occupied, the average temperature is above 25°C in both the staff room and the cellular office, indicating relatively high temperatures inside of these spaces. The highest indoor temperature in the specified spaces reached during the monitoring period is above the upper comfort limit recommended by CIBSE, i.e. 26°C, and for the east-facing staff room it was even recorded at 31.8°C, which exceeds the upper comfort limit by nearly 6°C. Hence, it can be assumed that the user who occupies the office (i.e. Mr R Shield) and the staff who often use the staff room could suffer some discomfort in summer due to high temperatures inside the room.

The line graph (Figure 4.2-18) displays a continuous two-week plot of temperatures recorded in all monitored spaces and the outside environment. The grey areas denote the period of time when the school was occupied. It can be seen that the temperature in the cellular office and the east-facing staff room was generally higher than the temperatures of the other two classrooms, which

corresponds to the previous finding.

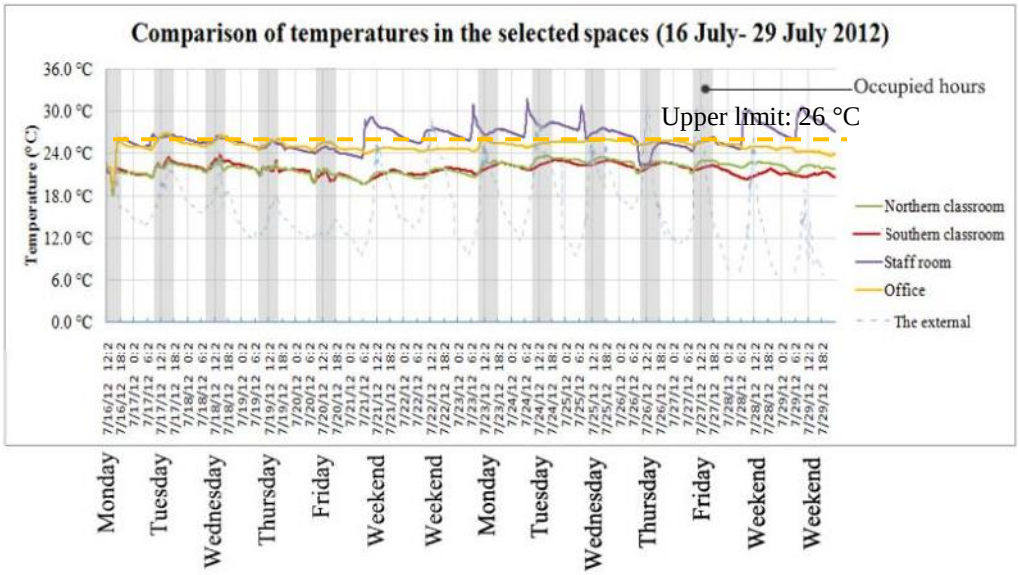


Figure 5.3-31: Temperatures recorded in the monitored spaces over two weeks in July 2012 (source: Author).

For the cellular office, although the temperature inside is on average within the comfort zone, the fluctuation of the daily temperature is very small. This is because the selected office (i.e. Mr R Shield's office) does not have any window openings facing the outside for daylighting and natural ventilation, but fully relies on artificial lighting and air conditioning. This is not an appropriate design for any working environment in schools, and should be rectified.

For the east-facing staff room, the daily temperature inside rises above 26°C on three occasions during the second monitoring week, indicating a relatively high chance for the space to become overheated. In these three days (i.e. between 23 July 2012 and 25 July 2012), the temperature in the staff room generally goes up to nearly 30°C in the morning and drops to between 26°C and 27°C after the room is occupied. It shows that the high internal heat gains are chiefly from the solar radiation rather than the occupants. In accordance with the glazing design

as well as the ventilators applied (i.e. the high-level clerestory windows) for the east-facing staff room (see Figure 5.3-32), it can be inferred that high heat gains in the staff room are chiefly due to solar heat gains from the large east-facing glazing in the morning periods as well as the internal heat gains from the occupants and the equipment installed in (i.e. computers and cooking facilities); larger ventilation openings are therefore needed. The findings about the internal thermal environment of the staff room and the office correspond to the POE results regarding thermal comfort in summer that majority of the school staff raised the overheating issue.



Figure 5.3-32: Glazing and ventilator design in the east-facing staff room (source: Author).

For the two standard classrooms, thermal comfort is generally achieved in the monitored period, indicating that the ventilation strategies worked effectively in terms of removing the potentially excessive heat gains from the external and the internal heat gains. According to the Optivent prediction analysis, thermal comfort in classrooms can only be achieved when both the single-sided ventilation and the cross-stack ventilation work effectively. Thus, it implies that, during the monitored period in July 2012, both the single-sided ventilation and the cross-stack ventilation work effectively to remove excessive heat gains in the monitored classrooms. In addition, it is interesting to find out that the temperature inside the north-facing classroom is on average higher than that in

the south-facing classroom. This could be potentially due to the use of solar-control glazing for the south-facing classrooms which effectively reduces the heat gains from solar radiation in the south-facing classroom in summer, and also may be due to additional heat gains in the north-facing classroom from having artificial lighting on or from using other equipment.

- Thermal performance in March

For the thermal performance of the school in the heating season, Table 5.3-17 shows the summary of the on-site measurement of the selected spaces between 15 March and 28 March 2012 when the school was occupied. The data for the staff room were missing, so only the data for the two classrooms and the office were analysed in this study.

Table 5.3-17: Summary of the on-site measurement for a two-week period in the heating seasons.

Room	T_{min} [°C]	T_{max} [°C]	T_{ave} [°C]	RH_{min} [%]	RH_{max} [%]	RH_{ave} [%]
Northern classroom	20.2	24.4	21.6	27.9	67.6	38.9
Southern classroom	**17.6**	23.5	20.5	29.1	66.4	41.7
Office	22.4	24.6	22.9	30.2	68.5	41.1

Figure 4.2-21 displays a continuous two-week plot of temperatures recorded in the specified rooms and the outside environment. It can be seen that the temperatures in the two classrooms were almost within the recommended comfort zone (i.e. between 19°C and 21°C) during the measurement period, indicating that thermal comfort was generally achieved in both the south-facing and the north-facing classrooms in this heating season.

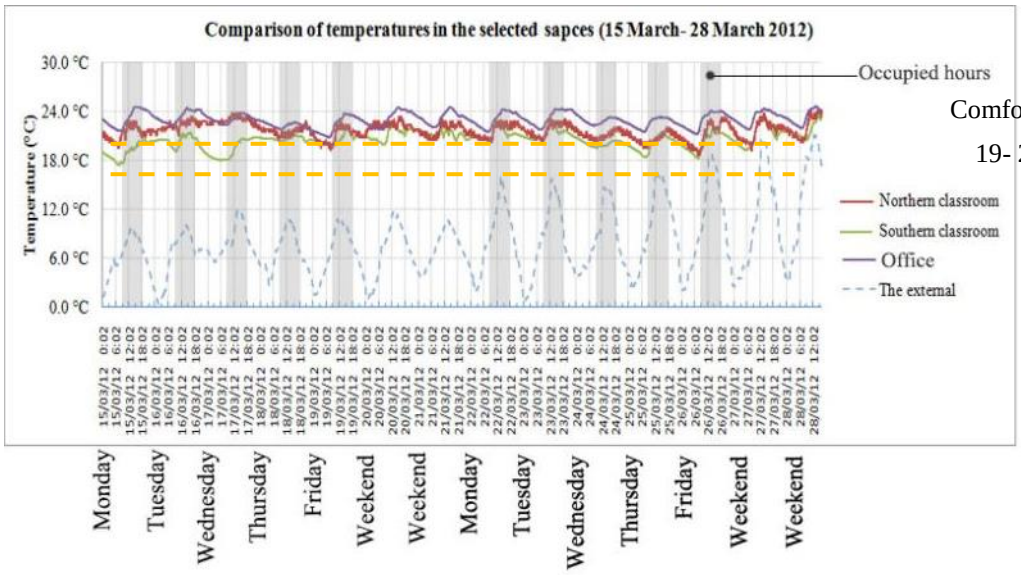


Figure 5.3-33: Temperature recorded in the monitored spaces over one week in the heating seasons (source: Author).

During the monitoring period, temperature in the north-facing classroom is on average higher than that in the south-facing classroom, which corresponds to the on-site temperature measurement in July 2012. This may be due to a number of reasons. For example, additional internal gains from a larger class size or artificial lighting in the north-facing classroom during the monitored period could cause higher internal temperature. Different occupant behaviours such as opening windows may also cause different indoor temperatures. In addition, according to the wind data of Nottingham in March (see Figure 5.3-34), the winds during the monitored period were more frequently from the south or the southeast, and the temperature of the wind was generally cooler than the temperature of the west winds. This could also cause relatively cooler temperature in the southern classroom in comparison to the northern classroom; however, the temperature difference is small and there is not much pressure difference.

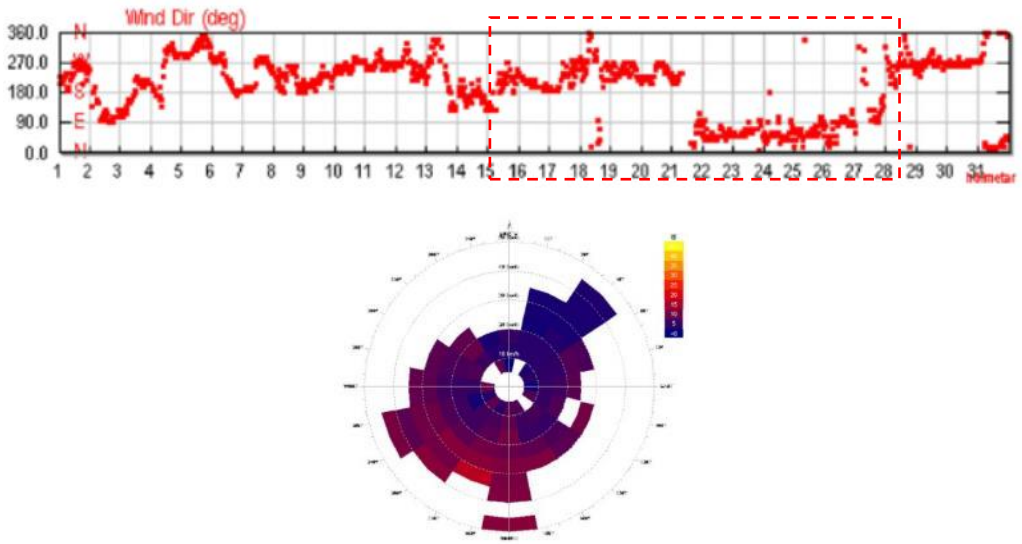


Figure 5.3-34: Wind direction and temperature of Nottingham in March (source: BBC weather data 2012 and CIBSE weather data 2005)

For the cellular office which is mechanically ventilated, the temperature in the office during the occupied hours is generally greater than the upper limit of the recommended comfort limit (i.e. 21°C), implying that although thermal comfort is achieved in the office, excessive heating may be provided and hence leading to high energy use.

- Summary of ventilation efficiency and thermal comfort

According to the prediction analysis of ventilation and thermal performance of the school provided by Buro Happold, the standard classrooms can achieve thermal comfort in summer based on the proposed natural ventilation strategies and glazing design, i.e. cross-stack ventilation during day and night time and to use solar-control glazing for the south-facing classrooms. However, the Optivent calculation results prove that thermal comfort in the southern classrooms cannot be achieved simply relying on single-sided ventilation or cross-stack ventilation based on the current opening design, as the sizing of the vents for natural ventilation is inadequate to remove the heat gains from the

occupants, equipment and solar radiation. Therefore, larger vent openings are required.

On the other hand, the results of the temperature and RH measurements taken in the selected spaces in March and July 2012 reveal that thermal comfort in the monitored classrooms can be generally achieved, although the indoor temperature of the northern classrooms could be slightly higher than the temperature in the southern classrooms. The temperature difference may be result of a number of reasons, such as different class size, additional heat gains from equipment or artificial lighting, and others. Additionally, different wind conditions in different seasons can also cause the temperature variation.

For the other spaces in the school, thermal discomfort due to the overheating problem generally exists, particularly in the east-facing staff room and some cellular offices. For some cellular offices which are mechanically ventilated, the design employed - that there is no window facing the outside and no natural ventilation provided - is not recommended in school design, and could be removed. For the staff room, considering of its orientation (i.e. east), external shading such as operable shading panels is suggested based on the current glazing design. Furthermore, larger sizing of ventilation openings may be needed to benefit the staff's thermal comfort as a result of relatively high internal heat gains can be obtained from the staff, computers and cooking facilities installed.

5.3.5 School E

The school generally relies on mechanical ventilation the whole year round, which could be potentially considered as a result of a lack of confidence in the

design team's ability to find a workable natural ventilation strategy which could simultaneously address the acoustic issues. For example, the Coventry University Library designed by Short Associates is adjacent to a very busy road but is naturally ventilated. Thus, the performance of ventilation in terms of air quality, ventilation rates and others will not be discussed in this study due to research feasibility.

The previous daylighting analysis identifies the potential overheating problem in the western and southern classrooms. To investigate whether or not these thermal issues exist in the school, four spaces distributed in different clusters were chosen as the monitored spaces; a western classroom for general teaching on the first floor in the middle cluster (i.e. classroom A), a southern classroom for general teaching on the third floor in the southern cluster (i.e. classroom B), an southern IT classroom on the ground floor in the southern cluster and an eastern office on the first floor in the middle cluster (see Figure 5.3-35).

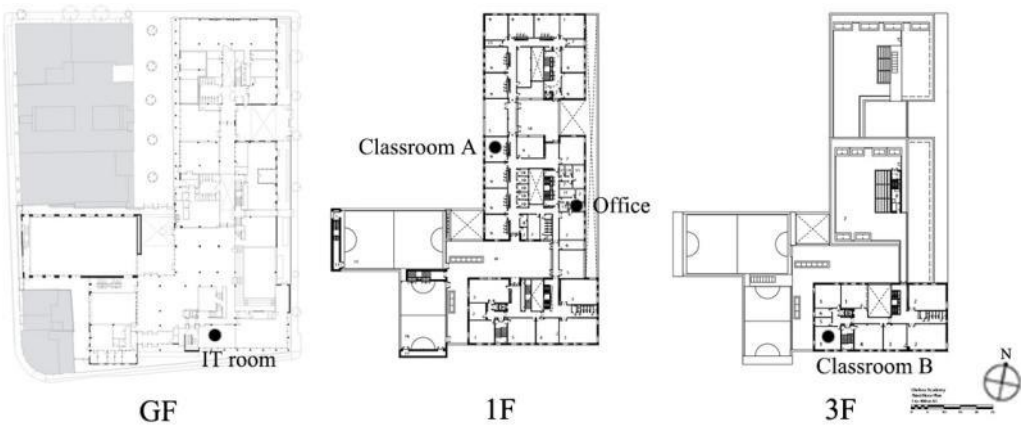


Figure 5.3-35: Locations of the selected space for thermal monitoring (source: FCBs).

To assess whether or not the overheating problem exists in these spaces, data had been recorded on site for two weeks in April 2012 when the external weather was generally mild and two weeks in the summer month when cooling

was required (i.e. July 2012). Because the indoor environment of the school is generally controlled and adjusted by the central mechanical system and the window openings in classrooms are quite narrow, the impact of the manual adjustment to the indoor temperature was not considered in this study.

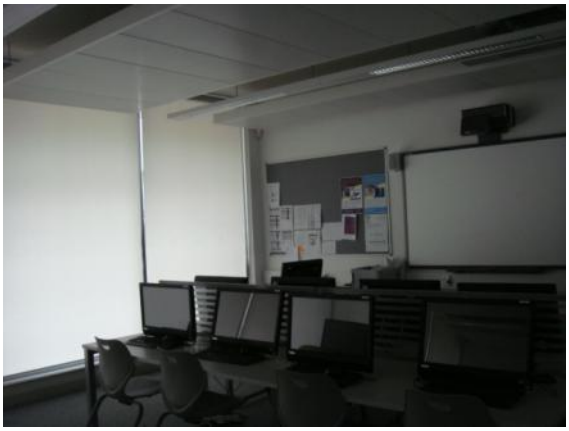



Figure 5.3-36: The interior of the office (left) and the IT classroom (right) (source: Author).

- Thermal performance in the mild season

Table 5.3-18 shows the summary of the thermal comfort results of the specified spaces for a two-week period between 2 April and 15 April 2012.

Table 5.3-18: Summary of thermal comfort results in April 2012.

Room	T_{min} [°C]	T_{max} [°C]	T_{ave} [°C]	RH_{min} [%]	RH_{max} [%]	RH_{ave} [%]
Western classroom	16.7	**28.1**	19.8	13.1	77.8	34.6
Southern classroom	16.7	21.5	19.3	19.6	60.9	35.6
IT classroom	15.6	22.9	19.3	20.2	66.7	38.5
Office	17.6	22.7	19.1	21	78.6	35.7

The highest indoor temperature reached during the monitoring period is 28.1°C in the western classroom, indicating that the users who occupy the western

classroom could suffer some thermal discomfort. The average RH of the monitored spaces is generally below the CIBSE criterion (i.e. 40%) so that the occupants could feel a dry atmosphere in the classroom in this season.

In accordance with Figure 5.3-37 that displays a continuous two-week plot of temperatures recorded in all monitored spaces and the outside environment, it can be seen that the differences in daily temperature of the monitored spaces are relatively obvious. The temperature of the western classroom (i.e. represented by the red line) is generally higher than the temperature of the other rooms, and even occurs above the upper limit, 26°C, once in the first monitored week. For the other monitored spaces, the indoor temperature is generally between 17°C and 23°C.

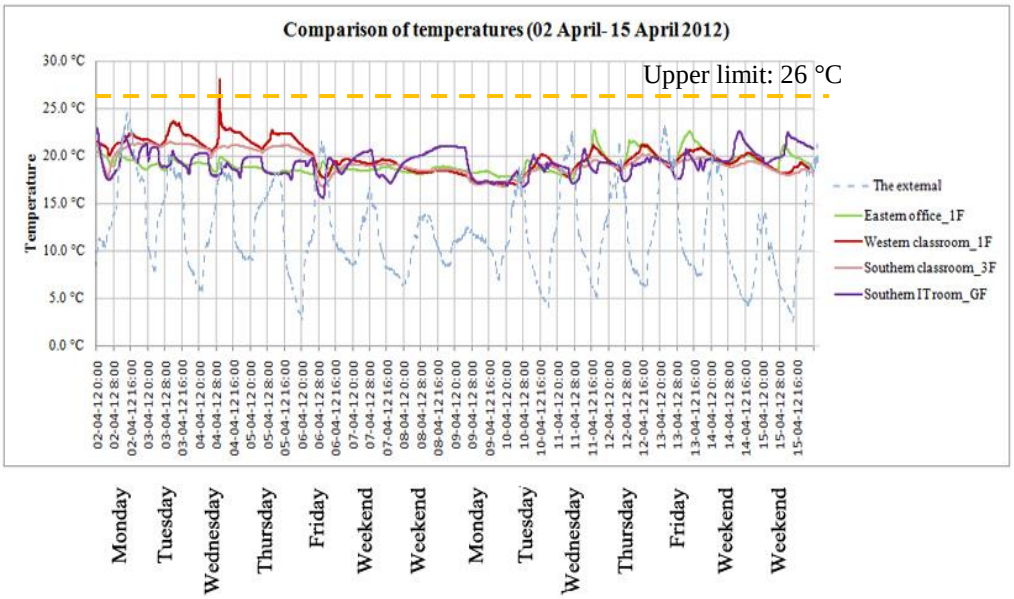


Figure 5.3-37: Temperature recorded in the monitored spaces over two weeks in the free-running season (source: Author).

The highest temperature in the western classroom was recorded one afternoon during the monitoring period, which corresponds to the assumption drawn from the previous daylighting analysis regarding classroom A that the western

classrooms could suffer the overheating problem in afternoon periods due largely to a combination of solar and internal heat gains. Additionally, the solar analysis for 12 April at 14:00 p.m. also proves that direct sunlight from the west can reach the western elevation of the school directly (see Figure 5.3-38).

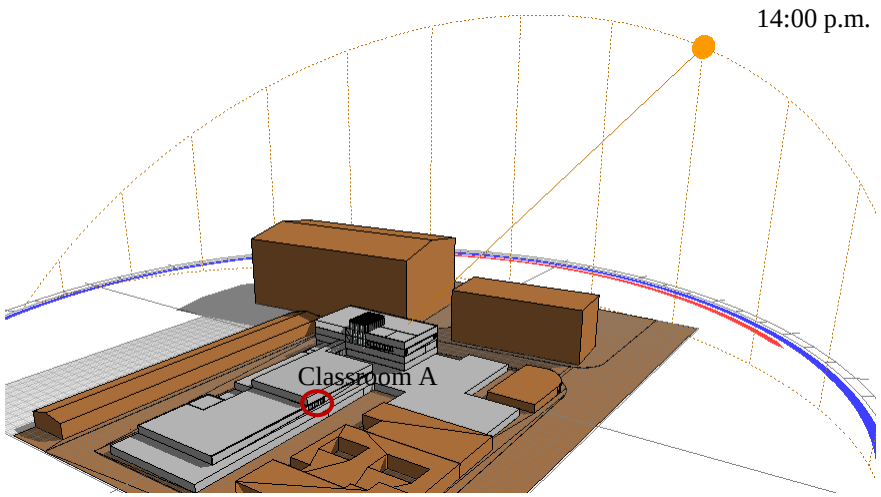


Figure 5.3-38: Solar analysis for 12 April at 14:00 p.m. sSource: Ecotect).

- Thermal performance in the summer month

Spaces in the school were divided into various zones in order to improve the efficiency of the central controlling system. Pre-cooled or pre-heated air will be specifically delivered to different spaces based on the indoor temperature as well as the concentration of carbon dioxide present. To evaluate whether or not thermal comfort can be fully achieved in the school in the cooling season, the on-site monitoring was also conducted in a two-week period in July 2012 for the defined spaces.

Table 5.3-19 displays the summary of the indoor temperature and relative humidity of the four spaces in the two-week period in July 2012 when the school was occupied, i.e. between 9 July and 22 July 2012.

Table 5.3-19: Summary of thermal comfort results in July 2012.

Room	T_{min} [°C]	T_{max} [°C]	T_{ave} [°C]	RH_{min} [%]	RH_{max} [%]	RH_{ave} [%]
Western classroom	20.6	25.4	23	37.5	87.1	53.6
Southern classroom	20.3	24.6	22.7	38.9	80.7	55.2
IT classroom	19.3	25.7	22.3	40.5	80.3	56.7
Office	20.2	25.6	19.1	37.4	89.9	55.1

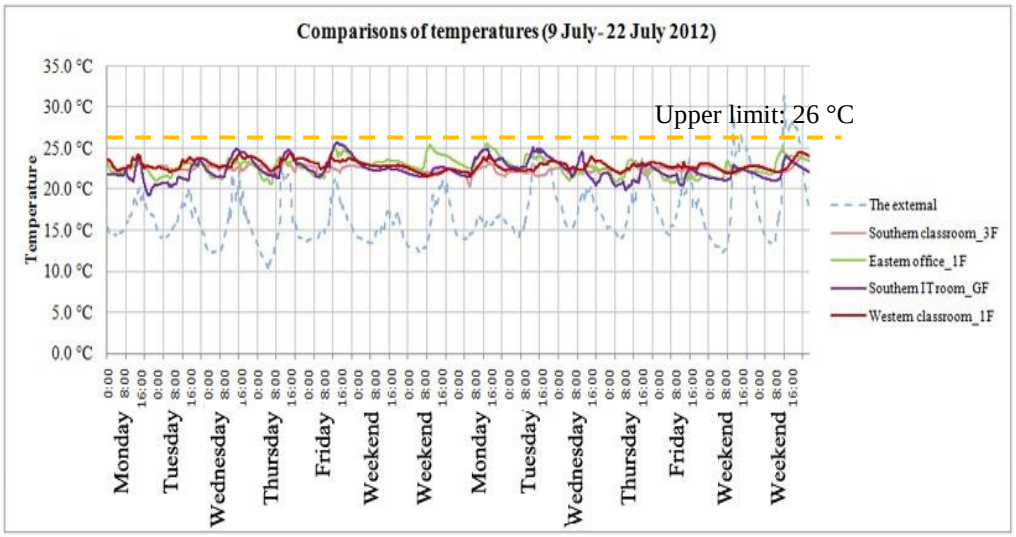


Figure 5.3-39: Temperature recorded in the monitored spaces over two weeks in the cooling season (source: Author).

Figure 5.3-39 illustrates the temperature of the four spaces recorded in the two-week period in July. Comparing this with Figure 5.3-37, the fluctuation of the lines in Figure 5.3-39 is not as evident as it is in Figure 5.3-37, denoting that the differences of daily temperature in the cooling period (i.e. July 2012) are smaller than those in the mild season (i.e. April 2012).

Reading from the graph, the temperature of the four spaces is generally controlled between 20°C and 25°C which falls within the comfort zone. The IT

classroom on the south gets the highest temperature (represented by the purple line) for most of the time in the recorded period. This is chiefly because of the heat gains from the computers and equipment installed in the classroom as well as the solar radiation from the southern sunlight via the large southern glazing (photos can be seen in Figure 5.3-36). As the school was air-conditioned during this monitored period, the above results prove that thermal comfort can be generally achieved in the school in the cooling period, but that solar gains, which could be avoided, are contributing to the cooling load that might be impacted on the energy consumption of the school.

- Summary of thermal performance

The thermal analysis proves the efficiency of the mechanical cooling system installed as well as the thermal mass of the building fabric. In the cooling-required months, the air-conditioning system and the central controlling system can work effectively to maintain the indoor temperature in most key areas in the school within the ranges of the comfort zone. Nevertheless, in the mild season such as April, it seems that thermal comfort cannot be fully achieved in the school, particularly in the western classrooms, and this is due largely to the overheating problem. The combination of the orientation and the glazing design is the chief reason for the overheating issues in the western classrooms, although the glazing design for the western classrooms can ensure sufficient daylighting. Based on the previous shading analysis, vertical shading for the western elevation could be considered for future improvement.

On the other hand, comparing the differences of the daily temperatures in the mild season and the cooling season, the variation of daily temperatures in the mild season is much more evident than it is in the cooling season. Therefore, it

can be assumed that, in the mild seasons, the cooling system may not be used to full capacity to adjust the indoor environment, and manual controls such as opening windows can also impact on the indoor thermal environment.

5.4 Energy performance

As it was mentioned previously, energy performance was only deemed as a supplementary factor to reveal building performance in this research project. Limitations, such as the absence of meter readings and energy breakdown, exist in the study, and should be completed in future work. In the case studies, when evaluating how efficiently the energy has been used in the selected cases, the actual energy efficiency of the five schools i.e. the DEC operational rating was compared with the DEC benchmark for typical schools in the UK. For the schools which have had both the DECs and EPCs at the time of this study (i.e. School A, B and C), the operational energy efficiency was compared with the favourable asset rating. Additionally, the annual carbon emissions from electricity and gas of the five cases were collected, in comparison with the relevant benchmarks.

5.4.1 School A

According to Section 4.2.3, school A did not perform as energy-efficiently as expected. High annual energy consumption due to the use of electricity was revealed in the case study, caused by either the use of ground source heat pumps for heating in the heating season or the frequent use of electrical lighting and equipment. Detailed analysis can be found in Section 4.2.3.

5.4.2 School B

The school received a score of 38 in the EPC assessment in December 2010, i.e. *rating B*, indicating that the favourable asset rating of the school should be better than the relevant benchmark for newly built non-domestic buildings (see Figure 5.4-1). However, Figure 5.4-2 displays the DEC rating of the school based on the assessment regarding the operational energy performance of the school between 2013 and 2014. The school received a score of 107 (i.e. Rating E) in the DEC assessment which was even poorer in comparison with the benchmark for typical schools, suggesting low energy efficiency and an obvious gap between the favourable asset rating and the operational rating.

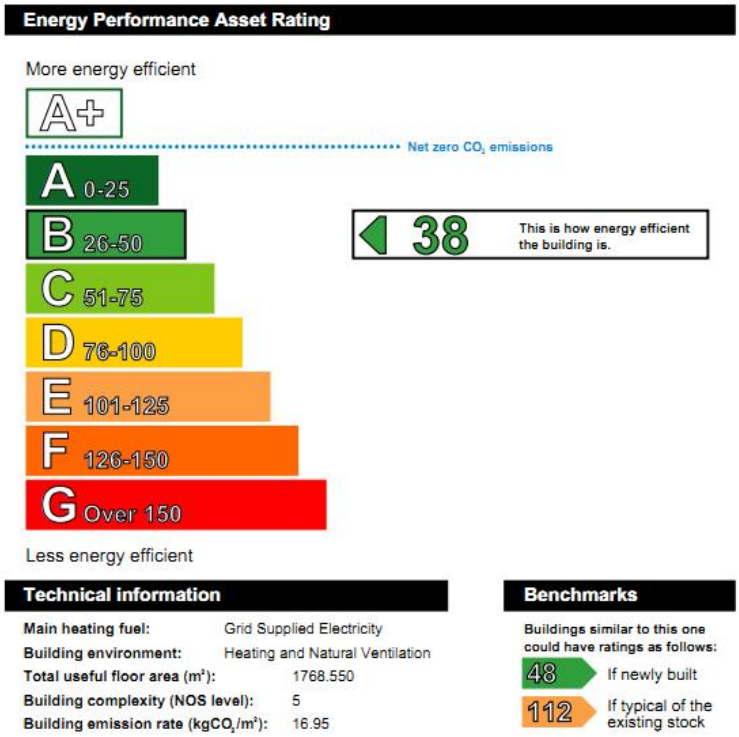


Figure 5.4-1: EPC of Sandal Magna School (source: SWA).

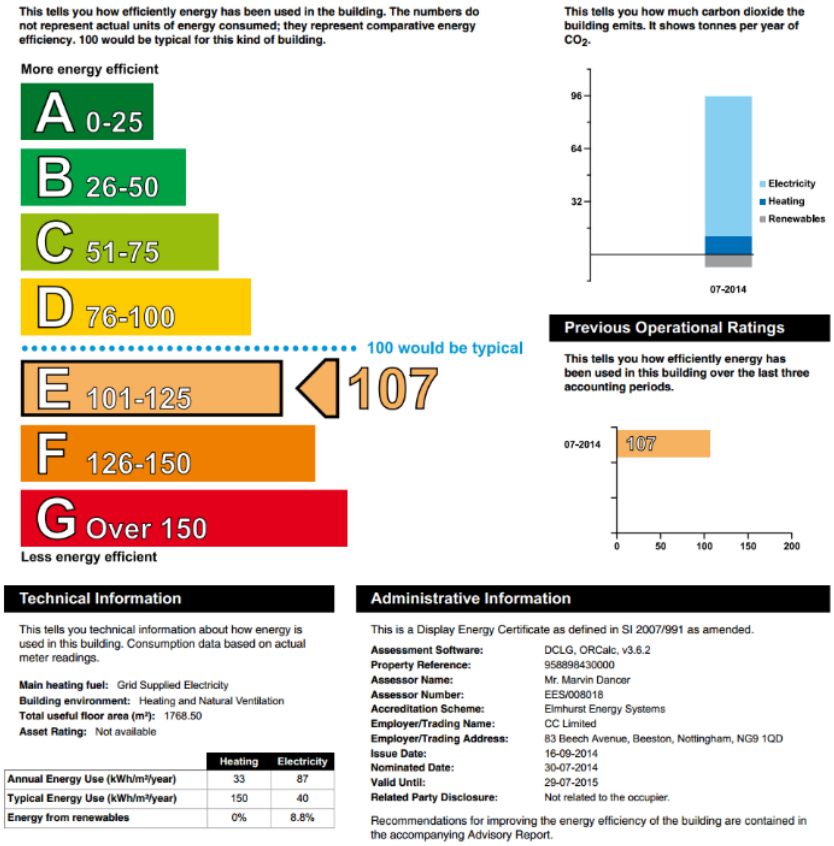


Figure 5.4-2: DEC of Sandal Magna Primary School (source: SWA).

The annual energy use of the school in terms of electricity and gas between 2013 and 2014 is displayed in Figure 5.4-3, compared with two benchmarks for primary schools in the UK, i.e. the benchmarks set out in the DEC for typical primary schools in the UK (2013) and the benchmarks provided by the Department for Education (DfE) for the top 10% of schools in the UK (2004).

The school's energy use of fossil fuels is generally less than the benchmarks. However, the energy use of electricity consumption of the studied school is approximately nearly twice as much as, and four times more than, the energy use of electricity consumption of typical primary schools and the top 10% of schools in the UK, respectively. In addition, the use of photovoltaic panels slightly contributed to the energy efficiency. The high demands on electricity

usage in school B were due largely to the use of the ground source heat pump and artificial lighting; however, a number of decisions made at design stages in terms of daylighting, ventilation and thermal aspect could have been taken to improve the school's performance radically, which have been demonstrated in the previous analysis.

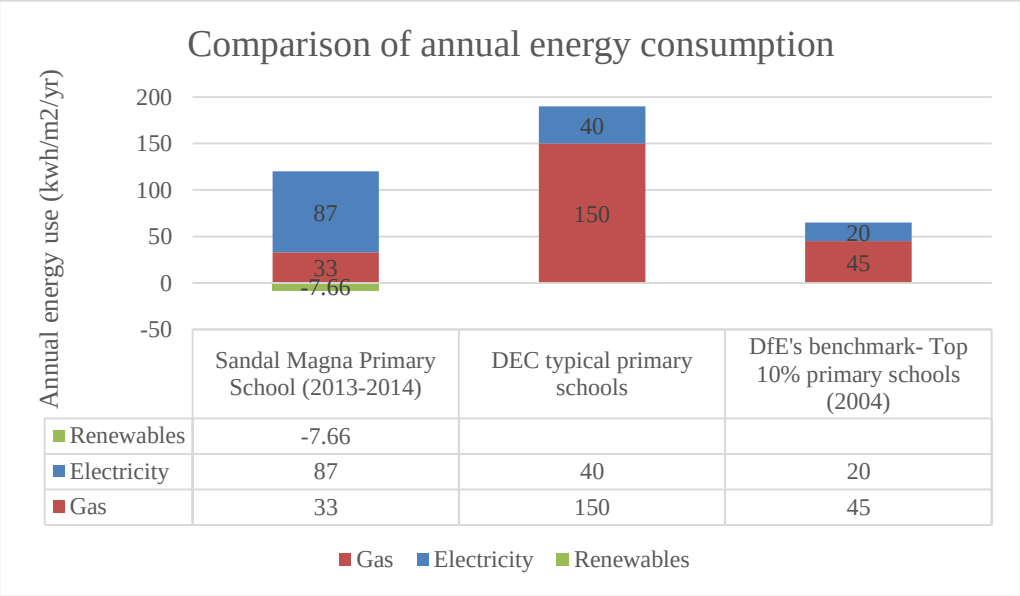


Figure 5.4-3: The comparison of annual energy use between Sandal Magna School and the benchmarks (source: Author).

In terms of the carbon emissions, the annual carbon emissions from the energy use of electricity consumption and fossil fuels (i.e. gas) were 44.1 and 5.2 $kgCO_2/m^2/yr$, respectively. In comparison with the top 10% schools, the carbon emissions from the electricity consumption of the school is around five times higher than the DfE's benchmark, while the carbon emissions from fossil fuels used by the school are five times lower than the benchmark due to the use of gas only for water-heating and cooling. The school was commented on as one of the "*most carbon efficient*" schools in England (Building, 2010); however, this could be too ideal an accolade, based on the above analysis.

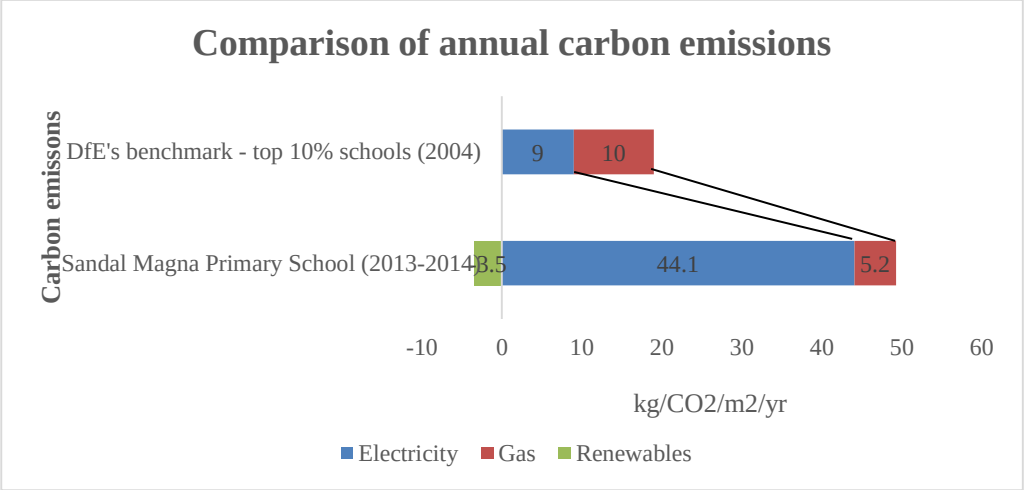


Figure 5.4-4: The comparison of annual carbon emissions between Sandal Magna School and the benchmarks (source: Author).

5.4.3 School C

Different rating results were obtained in the EPC and DEC assessment of school C that the school achieved: *Rating A* (i.e. the score of 24) and *Rating C* (i.e. the score of 68) in the EPC and the DEC assessments, respectively (refer to Figure 5.4-5 and Figure 5.4-6). Even though the result of the DEC assessment shows that the energy performance of the school is better than typical primary schools in the UK, we can still confirm that a gap exists between the actual energy performance of the school and the favourable asset rating.

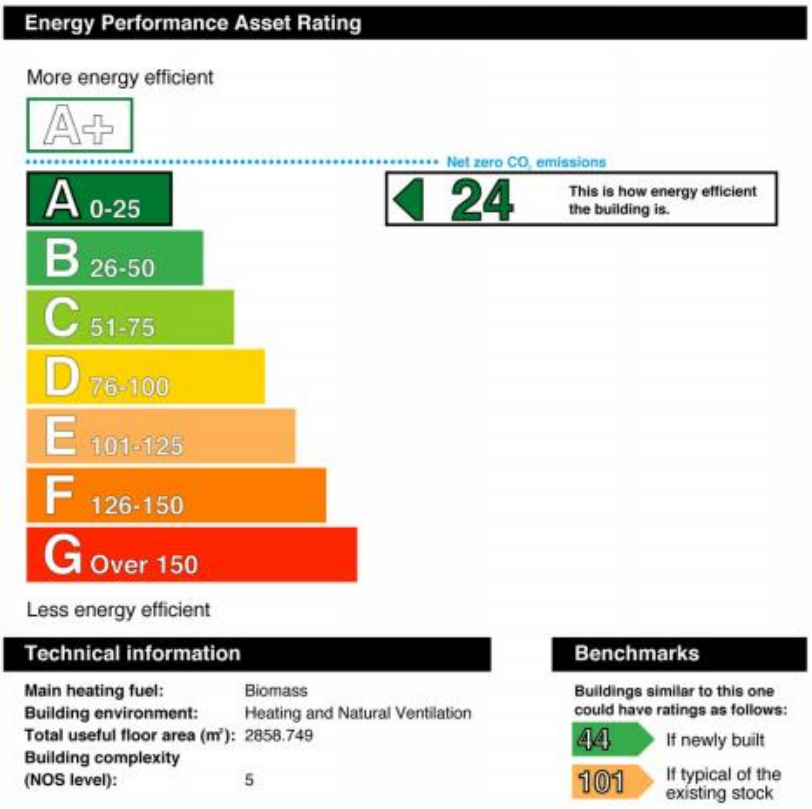


Figure 5.4-5: Theoretical energy Performance Certificate's rating of St Luke's Primary School (source: Architype).



Figure 5.4-6: Display Energy Certificate's rating of St Luke's Primary School following occupation (source: Architype).

Based on the energy consumption data provided in the DEC assessment results, the annual energy use of the school in terms of gas and electricity between 2010 and 2011 is displayed in Figure 4.2-23, compared with two benchmarks for primary schools in the UK, i.e. the benchmarks set out in the DEC for typical primary schools in the UK (2011), and the benchmarks provided by the Department for Education (DfE) for the top 10% schools[1] in the UK (2004). Based on the benchmarks, it can be seen that, normally, primary schools' energy use of gas consumption is larger than their electricity consumption.

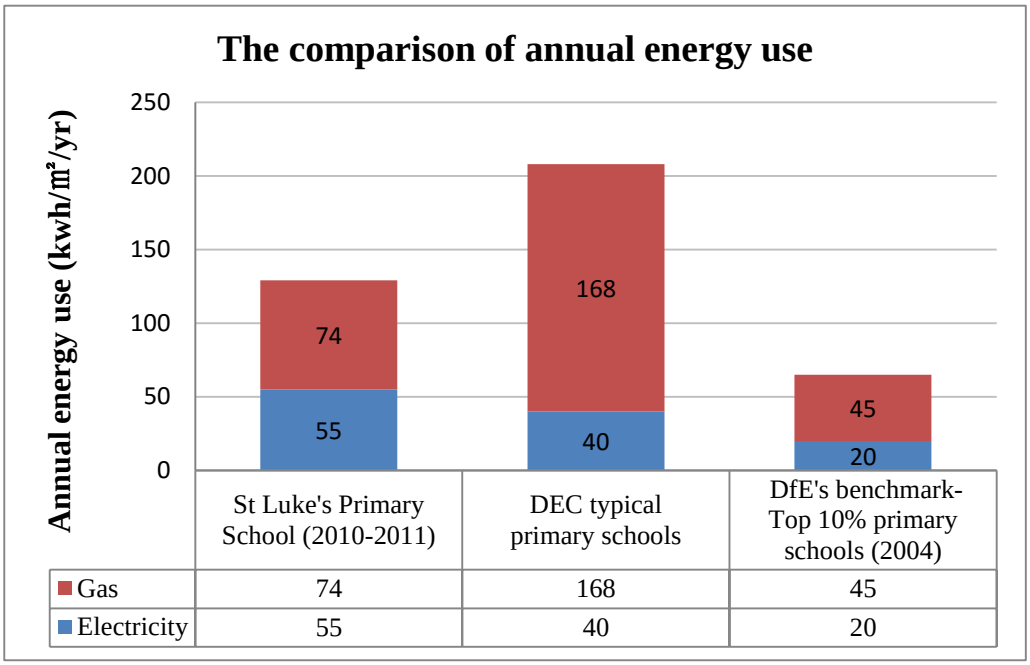


Figure 5.4-7: The comparison of annual energy use between St Luke's Primary School and benchmarks (source: Author).

The school chiefly uses a biomass boiler as the primary source for water heating supplemented by an additional gas boiler. Reading from Figure 5.4-7, the energy use of gas consumption of the case study school is only 19

[1] Based on the DfE's *Energy and Water Benchmarks for Maintained Schools in England 2002-2003*, the schools in the top 10% represent those that achieved the least energy consumption across all UK schools.

kwh/m^2/yr greater than its energy use of electricity consumption, which appears to be largely a result of the use of the biomass boiler that reduces the school's heating consumption from gas. Comparing the school's energy use of electricity with the benchmarks indicates a relatively poor performance, as the electrical demand of the school is nearly a three times as much again as the energy use of electricity consumption of the top 10% of schools in the UK and 15 kwh/m^2/yr higher than the DEC typical primary schools.

In terms of the carbon performance of the school, the comparison results between the school's annual carbon emissions (2011) and the DfE's benchmark for the top 10% schools in the UK (2004) are illustrated in Figure 4.2-24. For St Luke's Primary School, the annual carbon emissions from the energy use of electricity consumption and fossil fuels (i.e. gas) were 27.6- and 6.03-kgCO_2/m^2/yr, respectively. In comparison with the top 10% schools, the carbon emissions from the electricity consumption of the school is nearly three times more than the DfE's benchmark, while the carbon emissions from fossil fuels used by the school are 50% lower than the benchmark due to the use of the biomass boiler.

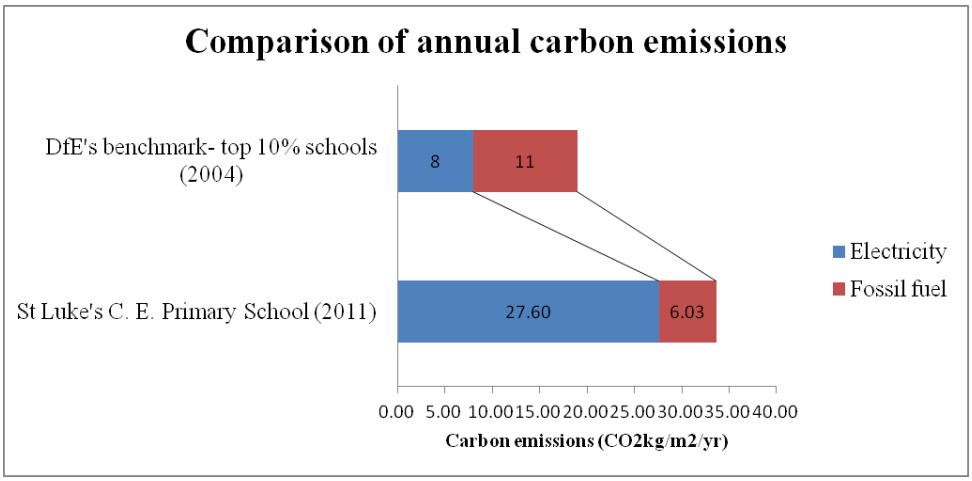


Figure 5.4-8: The comparison of annual carbon emissions between the school and the DfE's benchmark (source: Author).

The study further compared the annual carbon emissions of the studied school with the DCSF's targets for new schools built in the UK. Figure 5.4-9 shows that the school's carbon performance is still falls short of the latest DCSF's targets, i.e. 10 $kgCO_2/m^2/yr$, although the school was the first primary school in the UK to receive the BREEAM "Environmental Excellent" rating, which indicates a very positive theoretical carbon performance (i.e. The BREEAM assessment is undertaken at the design stage).

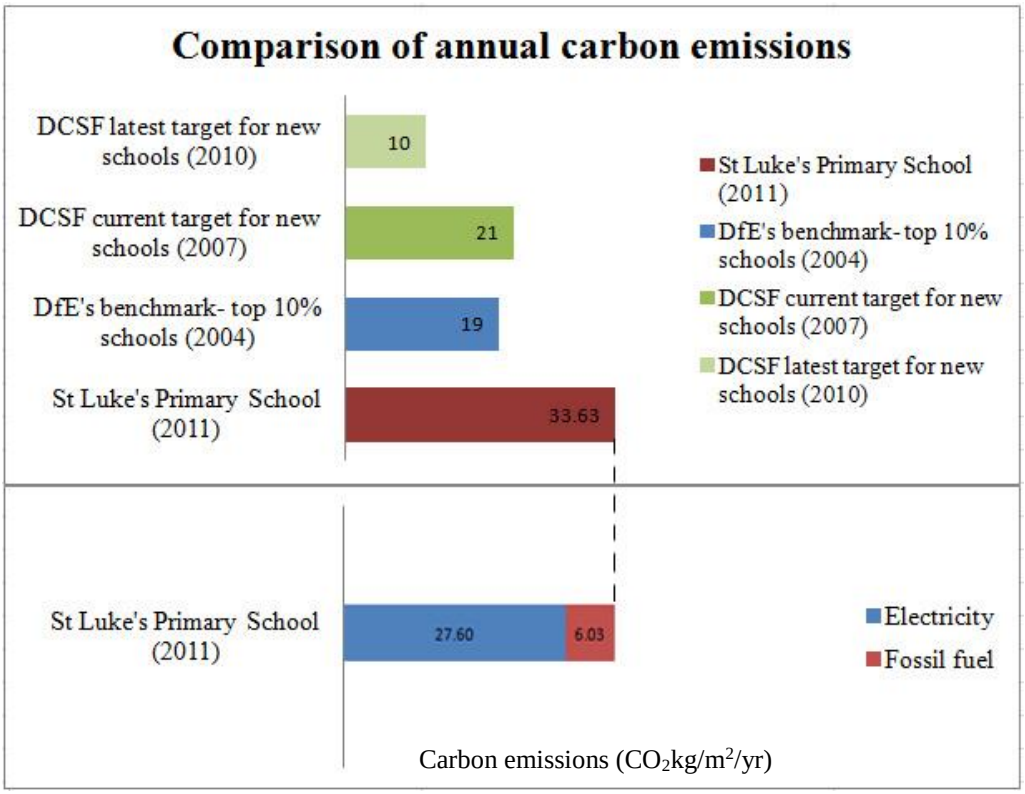


Figure 5.4-9: The comparison of annual carbon emissions between the school and the DCSF's targets (source: Author).

According to the POE conducted by Architype, the architects found that the electric usage is higher than hoped, and this is due largely to the overuse of artificial lighting. Therefore, the school users including the staff and pupils

were engaged in the energy management process and were mentored through Architype's 'soft-landing' approach to learn to habitually switch lights off (Architype, 2014). Further evaluation of the energy consumption of using electricity should be conducted to review whether this potential improvement work effectively.

- Summary of school C's energy performance

The gap between the factual energy performance of the school and its predicated energy performance implies that EPC assessments may predict an optimal performance of the building only when all controls are operated without mistakes. However, DEC can represent the realistic performance of the building and potentially reveal the existing problems. According to the DEC results, the actual energy use of the school in terms of electricity consumption is much higher than the relevant benchmarks, and the carbon performance of the school is also far from the Government's target.

Architype's 'soft-landing' approach helped them to find out the existing issue of the school's energy consumption that could be due to the excessive use of artificial lighting, so relevant solutions were conducted by the designers, such as mentoring the school users to habitually switch off lightings when the school is not occupied. According to the sixth steps of 'soft-landing' approach[2], a further evaluation of the actual building performance is required after the designers guide the building occupants to operate the building properly. Consequently, a more detailed and extended monitoring programme may be required to establish whether further improvements in performance could be achieved after the occupants were taught to manage the school.

[2] Detailed information of 'soft-landing' approach can be found in Chapter 3.

5.4.4 School D

The DEC assessment regarding the energy efficiency of the school was conducted in December 2012, three years after the building became occupied. Based on the assessment results, the school achieved *Rating E* (i.e. the score of 107) in the DEC, indicating that the energy performance of the school is actually slightly *worse* than typical secondary schools in the UK, which falls far short of the Government's target for low carbon schools. Detailed information of the DEC of the school can be found in Figure 5.4-10.

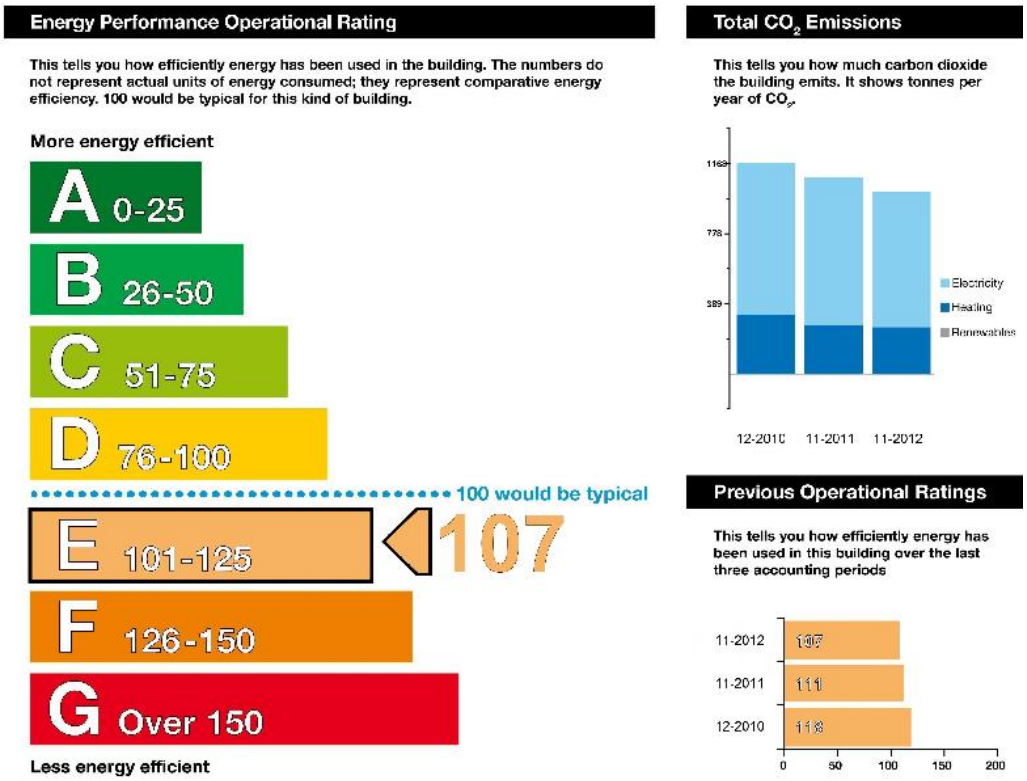


Figure 5.4-10: Display Energy Certificate of school D (source: P&P).

Figure 5.4-11 shows the annual energy use of the school in terms of gas and electricity between 2011 and 2012, compared with two benchmarks for secondary schools in the UK, i.e. the benchmarks set out in the DEC for typical

secondary schools in the UK (2012) and the benchmarks provided by the Department for Education (DfE) for the top 10% schools in the UK (2004).

Reading from Figure 5.4-11, comparing the school's energy use of gas with the benchmarks indicates that the performance of the school in terms of consuming gas is better than that of typical secondary schools but worse than the performance of the top 10% of secondary schools in the UK. As the heating source of the school is several gas-fired boilers, it can be inferred that to use more efficient boilers may improve the school's future gas performance. On the other hand, it is noteworthy that the energy use of electricity consumption of the studied school (i.e. 94 kwh/m^2/yr) is almost the same as its energy use of gas consumption (i.e. 92 kwh/m^2/yr), which is nearly twice that of the typical secondary schools and even over four times higher than the top 10% of secondary schools in the UK. This appears to be largely caused by the artificial lighting and the use of air conditioning in the school.

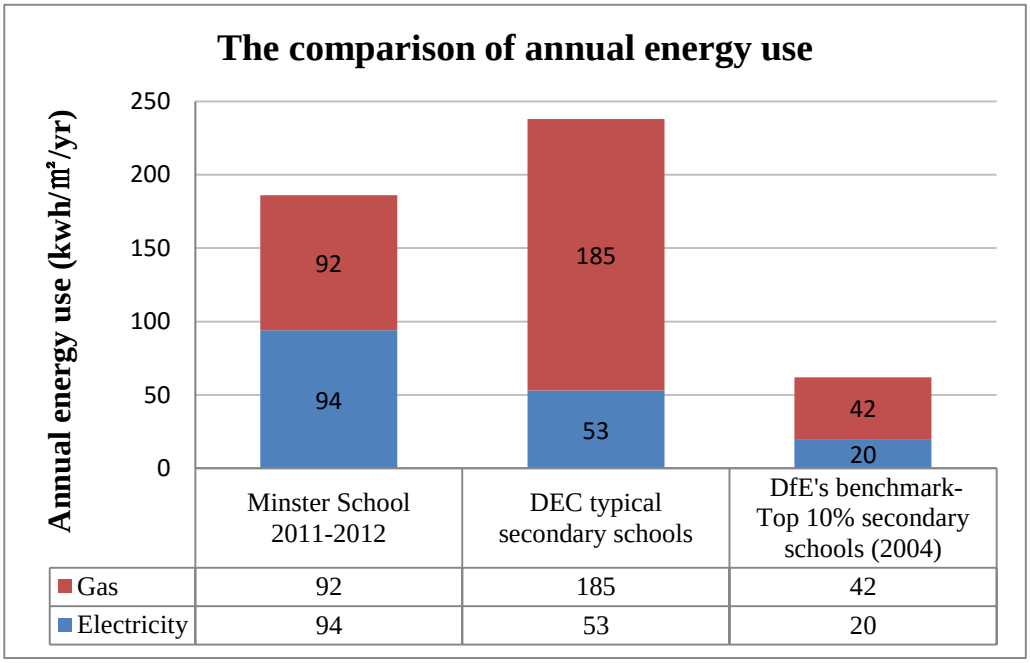


Figure 5.4-11: The comparison of annual energy use between Minster School and industry benchmarks (source: Author).

In terms of the carbon emissions, the comparison results between the school's annual carbon emissions (2011-2012) and the DfE's benchmark for the top 10% secondary schools in the UK (2004） are illustrated in Figure 5.4-12. For Minster School, the annual carbon emissions from the energy use of electricity consumption and fossil fuels (i.e. gas) were 48.5- and 17.1-kgCO_2/m^2/yr, respectively. In comparison with the top 10% schools, the carbon emissions from the electricity consumption of the school is nearly six times more than the DfE's benchmark, and the carbon emissions from fossil fuels used by the school are 6 kgCO_2/m^2/yr more than the benchmark.

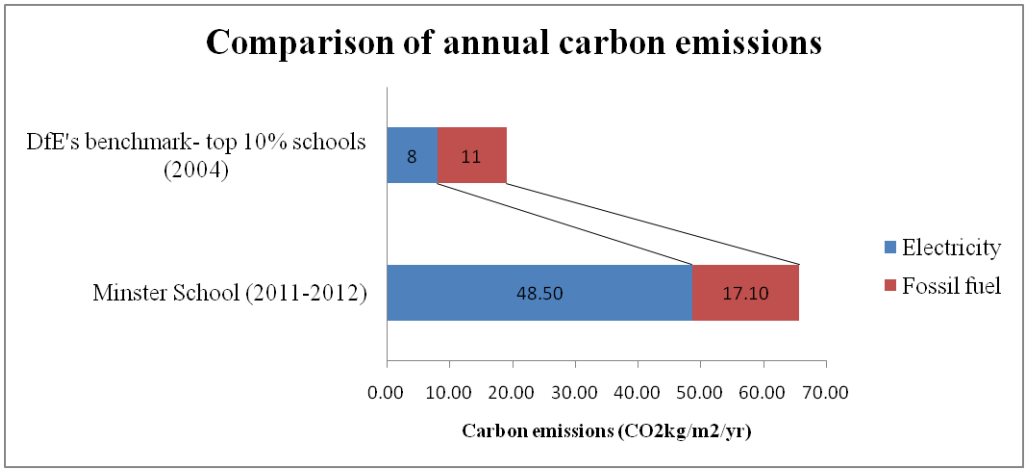


Figure 5.4-12: The comparison of annual carbon emissions between the school and the DfE's benchmark (source: Author).

Figure 5.4-13 further illustrates the comparison of the annual carbon emissions of the school (2011/12) with the DfE's benchmark for new schools built in the UK. The *Zero Carbon Task Force* requires that all new schools built after 2013 should reach the target of 10 kwh/m^2/yr (DCSF, 2010). Although the school under study was built before 2013, the annual carbon emissions of the school (i.e. between 2011 and 2012), i.e. 65.6 CO_2kg/m^2 /yr, are over six times higher than the DCSF's target, indicating a large gap that should be filled. This

implies that the school design in terms of daylighting (to reduce artificial lighting) and ventilation performance (to minimise mechanical ventilation) is very significant in minimising electrical energy consumption.

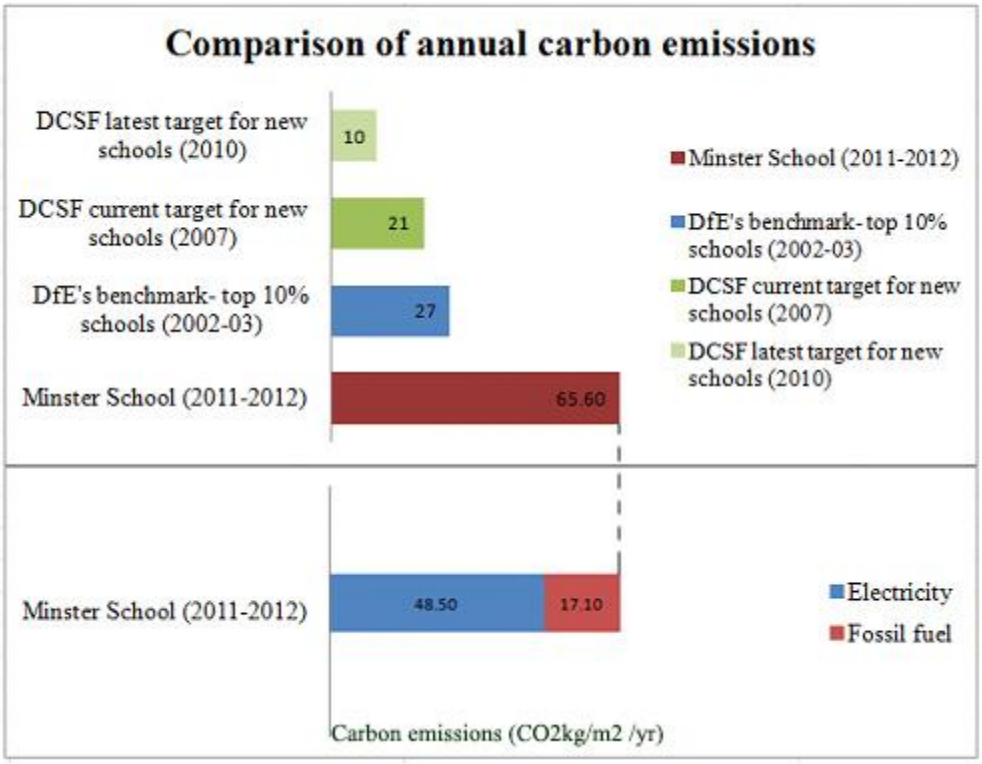


Figure 5.4-13: The comparison of annual carbon emissions between Minster School and the benchmarks (source: Author).

- Summary of energy performance

Although the school was designed to perform sustainably and received the BREEAM rating as 'very good', the above analysis with regard to the energy and carbon performance of the school implies a large gap between the design intent and the actual energy performance. The high demand for electricity due largely to the artificial lighting and air conditioning could potentially have been reduced by a more rigorous evaluation of the daylighting at the design stage, and by avoiding the use of mechanical ventilation and cooling.

5.4.5 School E

At the time of the study, Chelsea Academy did not have the DEC assessment of the actual energy performance. Instead, an Energy Performance Certificate (EPC) was issued in January 2011, representing the favourable asset rating of the school building. The school received a score of 39 in the EPC assessment, i.e. rating B, indicating that the energy efficiency of the building fabric and the heating, ventilation, cooling and lighting systems should be better than the relevant benchmark for newly built non-domestic buildings, i.e. Rating C with the score of 54 (see Figure 5.4-14).

Due to confidentiality issues, the factual energy consumption of the school was not acquired in this study, so it is difficult to evaluate the performance of the mechanical systems used for heating, cooling and ventilation. This is one of the limitations of this research, i.e. the absence of dome essential data. However, a recommendation report to improve the school's energy performance was obtained together with the EPC. The recommendations provided by the EPC assessor were based on the on-site observation and computerised assessment.

According to the recommendation report, some strategies were suggested to improve energy efficiency of the school as well as to reduce carbon emissions. For a short payback (i.e. less than three years), the heating boiler plant was suggested to be replaced by a high efficiency type. For a medium payback (i.e. between three and seven years), it was recommended that the energy source be switched from gas to biomass, and for a long payback (i.e. more than seven years), the upgrade of the chiller plant as well as the replacement of a current boiler with a condensing heating boiler was advised by the assessor. However,

these recommendations only relate to the building's services. The design of the building itself in terms of building form and fabric, plans and sections, could have been modified at design stages to reduce both heating and cooling load, and probably save capital cost.

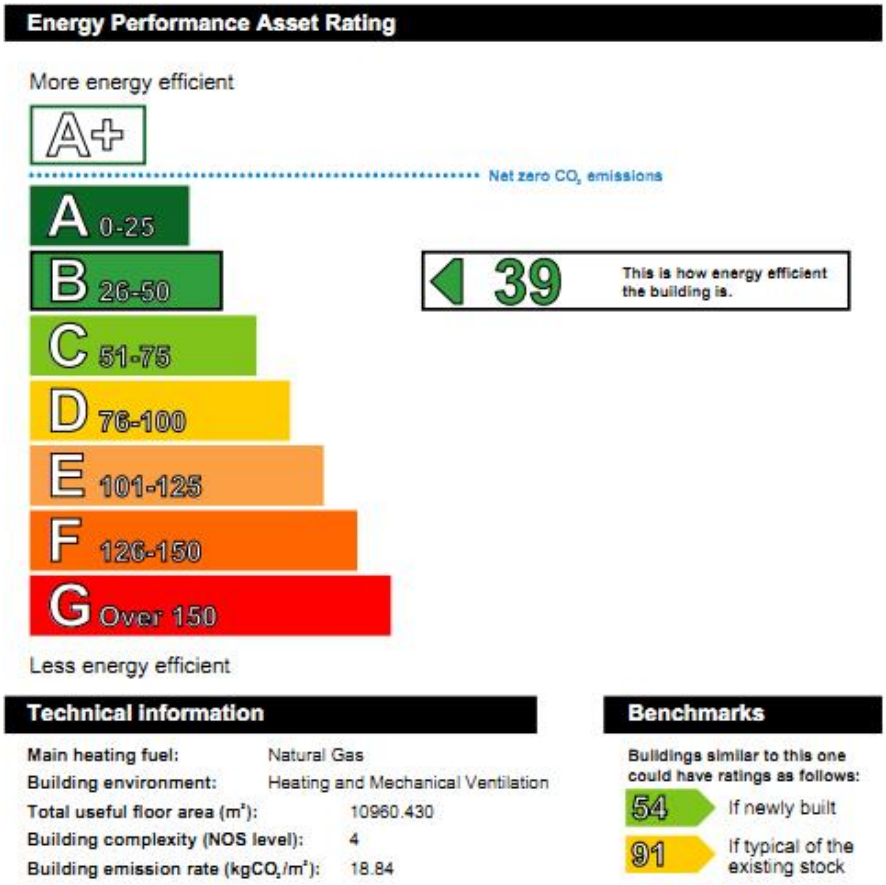


Figure 5.4-14: EPC of Chelsea Academy (source: FCBs).

5.5 Summary of technical performance

Based on the evaluation results of technical performance of the schools studied, not all the schools studied performed environmentally well, particularly the school B and D. Gaps between design intent and actual environmental performance were revealed from most of the case studies. The design decisions

related to the property of the environmental strategies employed was deemed as one of the most important factors impacting on environmental performance in use. In addition, the user operation, building management and controls played essential roles in determining the schools' energy performance.

The following content summarises the technical performance of the four schools studied, except school A.

5.5.1 Technical performance of school B

To echo the outstanding sustainable performance of the original Victorian school, SWA closely worked with the external consultancy - Max Fordham - and used a combination of passive strategies and innovative technologies in the design of the new Sandal Magna School. The intention was to create a sustainable learning environment with good energy and carbon performance. In addition, the school was designed to act as a "teaching and playing tool" in order to exhibit how the school building works every day to both children and adults who use the school. The design received several awards because of its 'design excellence' and environmental awareness.

To achieve optimal daylighting, the school was designed to be primarily daylit via the current daylighting design. According to the calculation results of DA and UDI metrics of the selected spaces, the issues of daylight insufficiency and unbalanced daylight generally existed in the north-facing learning spaces. Although some supplementary strategies, such as the south-facing rooflights for classrooms and the north-facing clerestory windows for group rooms, were added by the architect to assist daylighting in the northern spaces, the period of time over which the required illuminance level (i.e. 300 lux) was achieved on

the analysis planes was still less than half of the working year. On the other hand, the luminance analysis for the selected classroom indicates the existence of harsh luminance contrast between the whiteboard and the surroundings when the artificial lighting is off. This is chiefly due to the combination of the orientation and the glazing design of the learning spaces as well as the fact that no external or internal shading is provided. It therefore can be inferred that less visual comfort was achieved in the northern learning spaces in comparison with the southern classrooms, and this could lead to low productivity of the users, as well as high electricity demand for the use of artificial lighting.

To improve daylighting performance of the school, the glazing design in the learning spaces should be improved. According to the evaluation results of daylight sufficiency in the classrooms studied, it can be inferred that larger glazing areas are required and the timber panels used in the classrooms are suggested to be replaced by glazing with internal shading attached, in order to maximise the internal daylight while avoiding the glare risk. In addition, the colour of the interior materials of the learning spaces could be changed into lighter colours for higher reflectivity. The metallic hangings on top of the classrooms and the group rooms could have been adjusted or removed in order to improve the reflective daylight inside of the learning spaces.

In terms of ventilation efficiency and thermal performance of the school, the main issue is the overheating problem in the southern block in both summer and winter seasons. Because no particular ventilation strategy was provided for the southern block and because the south-facing glazing is exposed to solar radiation almost the whole year round, the ventilation rate achieved in the southern spaces was insufficient to remove excessive heat gains from the occupants, along with solar radiation. This finding corresponds to the school

staff's feedback regarding thermal comfort of the school, as a majority of the staff claimed that "*it is too difficult to concentrate on work in summer when rooms are too warm*" (Staff, survey, October 2012).

For the northern classrooms where natural ventilation was particularly designed to be driven by the stack effect, the air flow rate achieved in summer was sufficient to supply fresh air to the occupants but not adequate to remove excessive heat gains from the occupants and solar radiation, based on the Optivent's calculation results. The effectiveness of the air intake units designed by Max Fordham was also reported as "poor" by the site manager, as some heaters installed inside of the air intake units are easily broken. In terms of air quality, another issue was also pointed out by the school staff - that cold draughts could be present in the winter months causing the classroom spaces to feel cold. This is due principally to the current 'chimney' design. Thus, to improve ventilation performance of the school, larger air inlets and outlets are required. Besides that, the outlet direction of the chimneys can be adjusted so that it faces in different directions to avoid the draught issue.

The school was designed to be as carbon efficient as possible. However, energy consumption of the school building in terms of electricity usage was four times higher than the DfE's benchmark, indicating that the use of electricity is quite high. This is due largely to the use of the ground source heat pump and the high demand of artificial lighting and other equipment, whereas the use of photovoltaic panels could generate a certain amount of electricity to compensate for the carbon emissions of the school.

Learning from Sandal Magna School, the evaluation results show a large gap between the design intents and the actual building performance. Although the

architect proposed a series of environmental strategies to optimise sustainable performance of the school, the performance analyses imply that the designer did not fully understand how to produce an environment-friendly school building. Design decisions were not adjusted obviously based on the performance prediction analyses carried out by Max Fordham, and the aftercare service such as on-site guiding and reviewing was not undertaken neither. Accordingly, it is clear that an understanding of the impact of different strategies on the quality of the indoor environment and on the building users' needs to be better mastered.

5.5.2 Technical performance of school C

To achieve the design and environmental targets, the design team worked closely with Price and Myers as the consultants, and employed several passive strategies such as daylighting, natural ventilation and a biomass boiler for water heating, to ensure the school's good performance. In addition, Price and Myers carried out a series of prediction analyses and assessed the school's performance in terms of daylighting and thermal comfort during the early design stages, in order to test the efficiency of the proposed strategies and to offer suggestions for future improvement.

According to the performance evaluation results, gaps between the design intent and the actual environmental performance indicate that some strategies employed in School C may need further improvement. For daylighting, the issue of periodic glare identified in the southern classrooms could potentially be resolved by internal blinds.

In terms of ventilation efficiency and thermal comfort, the Optivent prediction

analysis indicates that the air flow rates required to remove excessive heat gains in the summer months can be generally achieved by the current ventilation strategies, but the issue of air quality in the northern classrooms on the ground floor and the issue of downdrafting from the occasionally summer winds from the northerly direction may exist in the northern classrooms due to the outlet design of the stacks. Enlarging the proportion of free opening areas of the stacks' outlets and adding more outlets facing different directions could improve ventilation performance of the northern classrooms. In addition, the issue of "*insufficient ventilation*" in the office spaces because of the limited-size glazing adopted in the offices was raised by the school staff in accordance with the occupant feedback. This is chiefly because the architects hoped to minimise the break of the building fabric; and hence, to a certain degree, sacrificed the window areas of the staff's offices to achieve this. This is a normal conflict between architectural design and building performance, but at least view access to the outside is recommended to be provided in office spaces in schools, considering of the staff's health and productivity.

To ensure good energy performance, a combination of passive strategies and innovative technologies, such as a biomass boiler, was applied by the design team. However, the DEC assessment shows that the school's energy performance was not as good as expected, particularly the electrical energy consumption, indicating gaps between the designers' expectation and the school's actual energy performance. Besides the DEC assessment, the design team also conducted a POE study by themselves, and learnt a lesson from the POE - that the occupants need to be persuaded to be aware of energy savings as a responsibility of all the occupants of the school, and that occupant behaviour is an essential part of this. Consequently, the designers provided a series of solutions to improve the school's energy performance, in accordance with the

approach of 'Soft Landings' that *the aftercare team should help the users and operators to get the best out their buildings*. The architects published how the passive strategies work in the school via cartoon notes stuck in the key areas of the school in order to raise environmental awareness of the school users and public visitors. They also invited the school users to join in the energy management of the school, and mentored both the staff and children to operate the building properly, i.e. habitually switching off artificial lighting when the spaces are not occupied.

Learning from St Luke's Primary School, it can be inferred that a success of school design is founded on the architect's comprehensive understanding of occupants' needs and the interactive relationship among different environmental elements such as daylighting, natural ventilation and thermal comfort in school design. Moreover, gaps between the designers' expectation and the actual energy performance of the school prove the importance of the service during the initial aftercare period in accordance with the 'Soft Landings' approach. According to the stage 4 of Soft Landings - *Initial aftercare*, at least one member of the design and building team is suggested to be present on site to help the occupiers to understand their building, and the facilities managers to operate its systems, for "*typically four to six weeks immediately after move-in*". This step could minimise the inappropriate operation to the building system and reduce the improper occupant behaviour in a relatively short period of time.

In the case of school C, the design team carried out some solutions after evaluating the school's energy performance, i.e. mentoring the school users' behaviour in terms of switching off lightings when the spaces are not occupied; nevertheless, further evaluation of the school's energy performance should be conducted after one or more years since the solutions have been carried out.

This corresponds to the stage 5 of 'Soft Landings' - *Years 1-3 Extended aftercare and POE*, suggesting that reviews of the building's actual performance and the occupant feedback can be moved from regular visits.

5.5.3 Technical performance of school D

The architects collaborated with the engineers Buro Happold, and produced a combination of passive strategies, i.e. daylighting and natural ventilation, and mechanical strategies, attempting to ensure the school's environmental performance as well as energy and carbon performance. A performance prediction analysis was undertaken by Buro Happold in the design process.

Details of inadequate environmental performance were revealed by the performance analyses. The environmental issues revealed include insufficient daylight and excessive artificial lighting in classrooms, and the inefficient ventilation and the overheating problems in the staff room as well as some offices. Gaps between the design intent and the actual building performance suggest that some strategies employed in the school have failed to perform well in practice. In mitigation, it is rare for design teams to have the time to undertake the level of detailed evaluation of daylighting or ventilation. There are many complex and interrelated factors involved in delivering both high quality design and good environmental performance, but clearly, careful performance prediction at design stage is critical.

In terms of the daylighting design, strategies like rooflights, clerestory windows and large windows have been applied in different spaces of the school. Classrooms with different orientations have similar sized windows while the south-facing glazing has lower solar transmission values. Based on the results

of the DA and UDI analyses for the two standard classrooms with different orientations, better daylighting performance was achieved in the north-facing classroom in terms of daylight sufficiency compared with that in the south-facing classroom, but the south-facing classroom had, comparatively, a more even daylight distribution. No particular shading was provided for the classrooms in the school except the very "*thin and ineffective*" internal blinds, as described by the school staff. Visual discomfort due to harsh reflections off the whiteboard and the surrounding walls can be found in the south-facing classrooms, indicating that further shading devices are necessary. In addition, this has resulted in a 'blinds down- lights on' syndrome which acted as one reason of high electrical consumption.

On the other hand, Buro Happold undertook the prediction analysis of ventilation performance of the school at the design stage. This prediction analysis implied that thermal comfort in summer for both the north-facing and the south-facing classrooms can be achieved by the current cross-stack ventilation during the day and at night – via the window openings and the chimneys located at the back of the classrooms. However, according to the Optivent prediction analysis, it seems that, in summer, thermal comfort of the school can only be achieved when both the single-sided ventilation and the cross-stack ventilation work effectively, which is different as the engineers' prediction.

Based on the indoor temperature data measured inside of the specified spaces, it proves that although thermal comfort can be generally achieved in the classrooms, the spaces designed for the school staff such as the east-facing staff room and some cellular offices have a high risk of being overheated in summer. This is due largely to the combination of the glazing design and the ventilation

strategies employed in these spaces. It implies that design strategies employed by the architects should have been in accordance with the specific use of the spaces (potentially internal gains) as well as the rooms' orientations (solar heat gains). In addition, it is noteworthy that several cellular offices of the school do not have windows facing the outside for daylighting and ventilation which is recommended to be improved.

Although the school received the BREEAM rating as ‘very good’, the DEC rating of the school (rating E) represents that the school’s environmental performance in terms of energy efficiency was even poorer than that of typical secondary schools in the UK. The annual energy consumption of electricity of the school is very high, and this is due largely to the fact that unsatisfactory daylighting has led to excessive use of artificial lighting and air conditioning has been applied to nearly 30% areas of the school. Furthermore, the carbon performance of the school is six times more than the DfE's benchmark, indicating a long way from meeting the Government’s low carbon target.

Learning from Minster School, the POE results show a large gap between the design intentions and the actual environmental performance, indicating a ‘poor’ understanding of the environmental design implications of design assessment. In this case, although performance prediction was conducted at the design stages by the engineers, the corresponding design modification provided by the design team was unable to deliver good building performance in use. It implies that the move towards low carbon schools has placed new demands on both architects and engineers, and it is apparent that embedding an understanding of the basic principles of environmental design within the design process is more difficult in practice than in theory. For instance, the aspects of daylighting, ventilation and thermal comfort should be considered as inter-related.

5.5.4 Technical performance of school E

To change the design challenges into opportunities, the FCBs collaborated with the external engineers, and integrated passive design (i.e. daylighting and thermal mass) with mechanical systems, intending to minimise the negative impact of the site and to produce a healthy and sustainable learning environment. The building was designed to be controlled and managed by mechanical systems principally. In order to achieve the acoustic requirement based on the relevant building regulations, high insulation with building mass (i.e. the exposed concrete structure) was generally applied for the school. Although FCBs has much experience of environmental design in school buildings, during the design process, only the assessment regarding the efficiency of the air conditioning system was conducted rather than other environmental performance analyses, such as the prediction of daylighting performance.

For environmental aspects, passive design strategies, such as daylighting and thermal mass, were utilised to adapt to the site limitations. In terms of daylighting, optimal orientation was not achieved due to the site constraints, but the architects used building massing to increase daylighting opportunities, as well as various daylighting strategies i.e. large windows for key areas and the introduction of three large-volume atria with glazing roofs. However, the evaluation results of DA and UDI metrics indicate that actual daylighting performance of the school was not good enough to reach the designer's design anticipation.

The daylighting analyses reveal several issues that could lead to visual or

thermal discomfort for the occupants, i.e. the occurrence of excessive daylight in the western and southern classrooms and the possibility of glare in the western classrooms, and others. The orientation of the school is one chief cause of the above issues. In addition, the current fenestration design plays a great impact on actual daylighting performance. For example, an average of three windows per classroom was applied in the school, but the architects reduced the number of windows for several northern classrooms on the third and fourth floors in the southern cluster, resulting in the occurrence of UDI-f in classroom C reaching above 30% and hence daylight insufficiency. This scenario could be simply improved by increasing the amount of windows or enlarging the daylighting access points; and it can be contended that architects should consider the fenestration design that can either have a positive impact on the appearance of buildings or benefit daylighting performance.

On the other hand, the use of another daylighting strategy, i.e. the insertion of three large-volume atria with glazed roofs, is worthy of a discussion. The school staff appreciated this design solution to a large extent, as they thought that these atria increased the levels of natural light inside the school and also created a welcoming atmosphere by introducing natural light into the communal areas of the school. According to the architect, the original intention of this strategy was to benefit the surrounding spaces by improving their daylighting performance, particularly for the surrounding classrooms, but the UDI results show that this strategy did not contribute much to improving daylight quality of the surrounding classrooms and hence a gap between the design intention and the actual daylighting performance.

In terms of ventilation and thermal performance of School E, the school staff pointed out the issues of insufficient air movement, the overheating problem

for some spaces, and the issue of dry air. The on-site monitoring results regarding the indoor temperature and relative humidity of four selected spaces correspond to the occupant feedback, indicating that thermal comfort can be generally achieved in the school when the heating or mechanical cooling systems run properly. Nevertheless, the overheating problem could occur in the western classrooms in the mild season when cooling is not provided, and this is due largely to the building orientation as well as to the fact that no external shading is provided.

To fully rely on mechanical systems to adjust the indoor environment is not a ‘traditional’ design approach for school buildings, as passive design has been considered as a more ‘sustainable’ method for school buildings in terms of energy consumption and carbon emissions generally. In the case of school E, the architects chose the mechanical systems for ventilation, heating and cooling as a priority to reduce the negative impact of the site limitations. This, to a certain degree, reduces the difficulty of maintaining and controlling the indoor environment of the school via building design, but yet could be resulted in insufficient confidence of the design team to deliver a successfully naturally-ventilated solution. On the other hand, building and maintenance cost are very significant factors of a building's environmental impact. Thus, it is reasonable to assume that the building, energy and maintenance costs of this mechanically-conditioned school will be significantly higher than for a naturally-ventilated alternative.

In terms of energy efficacy of the school, although the EPC shows that rating B could be achieved, this result is only a theoretical calculation result based on the strategies employed rather the real energy consumption of the school. DEC should be conducted for the school to reveal its practical energy performance in

accordance with the Government's requirement that non-domestic buildings which areas are above 1,000 square metres should have DEC assessment.

The case study of School E raises an interesting issue of the viability of naturally-ventilated buildings in urban centres. Mechanical solutions are not the only answer, particularly when the mechanical system itself is regarded as a source of unacceptable noise. Thus, it can be inferred that architects should have more comprehensive knowledge to address various environmental issues in building design, for different context.

Chapter 6 Architectural performance analysis

According to Cooper (2001), Boardass and Leaman (2005) and Gupta and Dantsiou (2013), POE studies can help building users to understand how to use/ operate buildings properly and assist designers to learn advantages and disadvantages of design strategies and technologies. Accordingly, the school users' perceptions regarding how the schools perform in practice was regarded as another essential when assessing building performance in this research project, besides technical performance.

In this chapter, feedback of the school staff and the headteachers regarding the school design and performance in use is presented in accordance with the POE studies, concerned as architectural performance. The POE studies undertaken were chiefly focused on environmental factors, i.e. lighting, air quality and thermal comfort, design-related and operation-related aspects, i.e. aesthetics, functionality, use of controls, handover issues, management and maintenance. The POE studies were primarily conducted via BUS Occupant questionnaires with the school users, i.e. school staff. In addition, separate interviews with the headteachers and site managers were carried out to explore the conditions of building operation and management.

6.1 School A

For school A, fifteen of the twenty school staff participated in the BUS Occupant survey, hence an effective response rate. The POE results emphasises the success of some design strategies used in the school, e.g. the spatial arrangement, the appearance of the school and interior design. Nevertheless,

some issues including too much natural light in classrooms, glare risk, thermal discomfort in the office and the lack of personal control over heating were revealed by the occupants, corresponding to the relevant analyses of technical performance. Detailed feedback can refer to Section 4.3.

6.2 School B

For school B, a survey with the headteacher and the site manager was conducted at the first visit to the school. The BUS Occupant questionnaire was carried out with all the school staff, and eighteen of the twenty five responses were collected.

6.2.1 Overall design quality

Based on the survey results, head teacher Julia Simpson (at the time of this study) was generally satisfied with the overall design quality of the school, particularly for the "*unusual*" design of the school in terms of its shape, appearance and the interior environment. She believed that the design of the school provides a delightful environment for the staff and children and increases the opportunity of delivering sustainable massages to the school users and the community (Julian Simpson, interview, 11 October 2012).

> *"Hardly a day goes by without a new revelation from this exciting building: it could be a previously unseen view of part of the building or the way that the building is being used by the staff or children. All the effort has produced a learning environment that has achieved and surpassed our wants and needs"* (ibid).

Even though a general satisfaction regarding the school design was achieved, the head teacher did point out several existing issues related to the actual performance of the school. In terms of the spatial arrangement, the sizes of the classrooms, the ICT space and the dining hall were considered as "*not sufficient*" by the head teacher, and she also pointed out that "*the design for the staff room and the office space does not provide a comfortable working environment*" (ibid.).

In terms of the environmental aspects, Simpson (2012) expressed that some spaces in the school do not have sufficient natural light and ventilated air, although the school was designed to be daylit and naturally ventilated, particularly at the southern block. In addition, some health issues relating to students were highlighted by the head teacher. She commented that the drainage system and the recycled rainwater system were initially designed with flaws and therefore affected the sanitary conditions in the toilets causing some health issues in the children (ibid).

6.2.2 Successful factors and existing issues

The BUS occupant survey with the school staff was carried out during the first visit to the school in October 2012; two years after the school was first occupied. The final response rate achieved 72%, so it can be assumed that the POE results can reflect how the school performs in practice based on the occupants' perceptions.

The overall feedback of the school staff was reasonably satisfactory, and most of the staff noticed improvements in the behaviour of the children since they moved into the new building. They considered that the design of the school was

"*eco-friendly*" and "*unusual compared with other schools*", and they were generally happy about the teaching environment and the classroom design (Staff, BUS survey, 2012). Figure 6.2-1 shows the summary of POE results regarding the chief variables in the survey. The red diamond symbols represent the aspect achieving the lowest level of satisfaction, so it can be assumed that the factors of the 'health', 'productivity' and 'air in winter' were identified as the chief problems existing in the school.

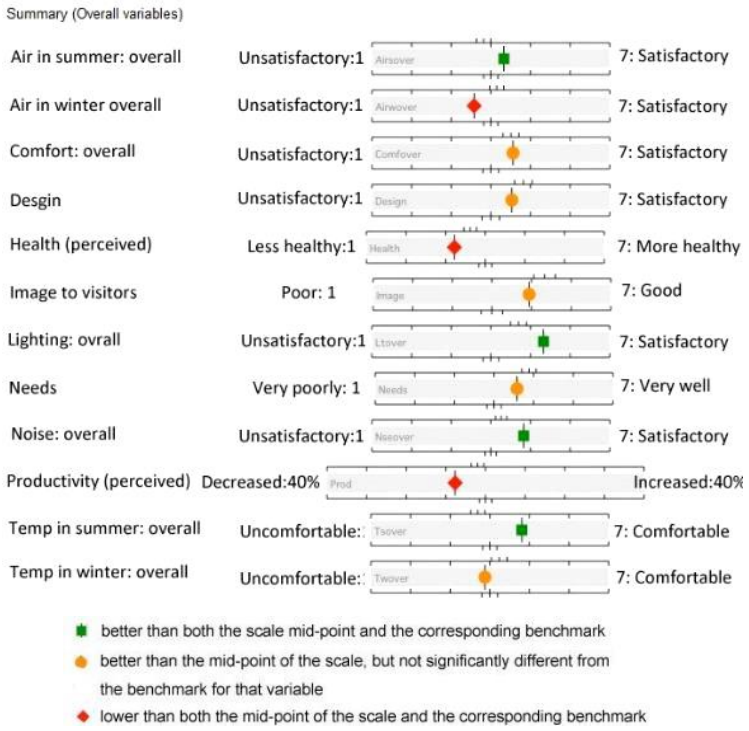


Figure 6.2-1: Sandal Magna School's POE summary of overall variables (source: Building Use Studies).

- **Successful factors**

- 'Unusual' and eco-friendly design

In the survey, the majority of the school staff expressed a positive attitude towards the school's appearance, although they thought that the school design was "*unusual*" compared with other schools but "*in a good way*". In addition, the eco-friendly features of the school were also highlighted by

most of the staff.

- Layout of the building and the group room design

The design of the group rooms received positive comments from 82% of the school staff. They thought that the provision of these group rooms offered extra 'set' spaces for smaller groups of students to work in and provided flexibility to spilt classrooms for certain subjects.

- Controls over lighting

As the lighting in the key areas of the school is manually controlled, the staff considered that it was more convenient for them to adjust the indoor lighting conditions themselves, rather than fully relying on the BMS system.

- **Existing issues**

- Limited spaces for classrooms, dining area, ICT space and storage

Several staff raised the issue that the size of the classrooms was quite limited. In addition, they commented on the changing curtain designed within classrooms: "*it makes it hard to see across the classroom because of the way it hangs*" (Staff, survey, October 2012). The size of the dining hall located in the middle block as well as the ICT space located in the resource zone beside the circulation was also considered as "insufficient" to fulfil the required demand. Furthermore, the lack of storage was also pointed out via the POE results.

- Insufficient natural light

Although satisfaction regarding the overall lighting condition in the school

was achieved based on the POE results, there are 58% of the staff pointing out the issue of "*insufficient*" natural light in the school, particularly for the northern classrooms. One member of staff reflected the views of others when they said "*the lighting in the school is generally good, but can be a little dark when there are no lights on in classrooms*".

- Air quality in summer and winter

The feedback regarding air quality and ventilation efficiency in the school is generally negative. For classrooms, the issue of variable air and cold draught in the winter from the chimneys was pointed out by the occupants. For the southern office and the staff room, all the staff commented that it is a very "stuffy" atmosphere with limited ventilation which makes it very difficult for them to concentrate on work.

- Overheating in the southern block and the low temperature in the northern block

The overheating issue in the southern block, i.e. the staff room and the office, was considered as a key problem in the school that badly impacts on the staff's productivity and comfort, particularly in the summer months. Over 75% of the staff considered that it was too warm to work in the southern office. On the other hand, the low temperature in the northern classrooms due to draughts, particularly in the winter months, was also raised by the staff. In addition, as the window openings in the classrooms are controlled by the BMS based on the indoor temperature and the concentration of carbon dioxide, sometimes windows will be automatically opened when the occupants do not expect or need them to, particularly in the cold winter.

> *"I found that it is harder to concentrate in the warm summer months when I am in the office, meeting room or the staff room, as the heat becomes unbearable at times…"*(ibid).

- Noise from the cloakroom

Although a series of acoustic strategies have been applied in the school, the issue of noise from the inside of the school was still revealed by the staff. Some staff reported that the hand dryers in cloakrooms can cause noise to the nearby classrooms, which can easily interrupt teaching or learning activities. Additionally, the noise from the adjoining office was also flagged up as an acoustic issue by some staff.

- Efficiency of the innovative technology

According to the interview with the site manager, he stated that "*it took a very long time for us to explore how to operate the building properly*" (Paul Andrew, interview, October 2012). In terms of the efficiency of the ground source heat pump as well as the photovoltaic panels, he also commented that *the electricity consumed by the heat pump was extremely high in the first school year*. The total electricity usage in the second running year was slightly better than it was in the first year after counting the electricity generated by the photovoltaic panels; however, the energy consumption of the school was 79.44 kWh/m^2/yr at the time of the study which is nearly twice more than typical primary schools in Wakefield. Detailed energy analysis can be found in Section 5.4.2).

6.2.3 Summary of the POE results

The POE results show that, in general, the school users were satisfied with the design quality of the school, particularly the appearance of the school as well as the 'sustainable' atmosphere delivered by the internal materials and the exposed construction details. On the other hand, several design and environmental issues were revealed based on the POE results which are chiefly relevant to the spatial arrangement and the indoor thermal environment. In terms of the design aspect, the limitation of the size of classrooms, dining area, and ICT space as well as office spaces was specifically pointed out by the staff.

Several environmental issues were highlighted by both the school staff and the site manager. For lighting in the school, the natural light in the northern classrooms was considered as insufficient by the majority of the school staff. In terms of ventilation efficiency and thermal comfort, the overheating issue and inadequate fresh air in the southern bock (i.e. staff room and offices), variable temperatures in different rooms, and draught issue in the classrooms were revealed in the POE results. It seems that thermal comfort in the school was not achieved in both summer and winter. This could be due to the inappropriate ventilation strategies applied in the school. In addition, some staff reported that noise from the hand dryers in the cloakrooms that adjoined classrooms affected lessons.

The school occupants were happy about the manual controls over the indoor environment to a certain degree, such as the manual switches for lighting in classrooms and group rooms. However, the site manager thought that *training for operating the building and the BMS system should have been provided by someone with the relevant expertise in the early stages when the school was first occupied, in order to manage and operate the building efficiently*. It is

inferred that the ‘Soft Landings’ (refer to Chapter 2) could be helpful to improve the school’s management and operation.

6.3 School C

For school C, the response rate of BUS Occupant survey was above 60%, indicating the survey results can generally reflect how the occupants perceive the school’s design and indoor environment. In addition, a short interview was conducted with a member of the management staff, Tom Edwards, at the author’s second visit to the school (2 April 2012), in order to investigate his satisfaction with the school design, particularly with regard to the efficiency of the sustainable strategies employed.

6.3.1 Overall design quality

According to the interview with Edwards, a relatively high satisfaction level regarding the school design was achieved among the school staff, children and parents. Edwards expressed that the school ethos and identity has been enhanced by the appearance of the school and its sustainable design theme. In addition, he highlighted the implementation of ‘sustainability’ in terms of educational meaning:

> *“The environmental considerations throughout the school, such as the environmental knowledge notes pasted on walls, really promote either students or adults’ environmental awareness when using the building every day”* (Tom Edwards, interview, 2 April 2012).

6.3.2 Successful factors and existing issues

Figure 4.3-1 summarises the occupant feedback on the chief variables in terms of architectural design and the quality of the indoor environment. As the scores of all the major variables listed below are better than those on the current BUS dataset, 'comfort' and 'satisfaction' seem to have been achieved in St Luke's Primary School in the main. One staff member said that "*it is a lovely building to work in*" (BUS occupant survey, 2012).

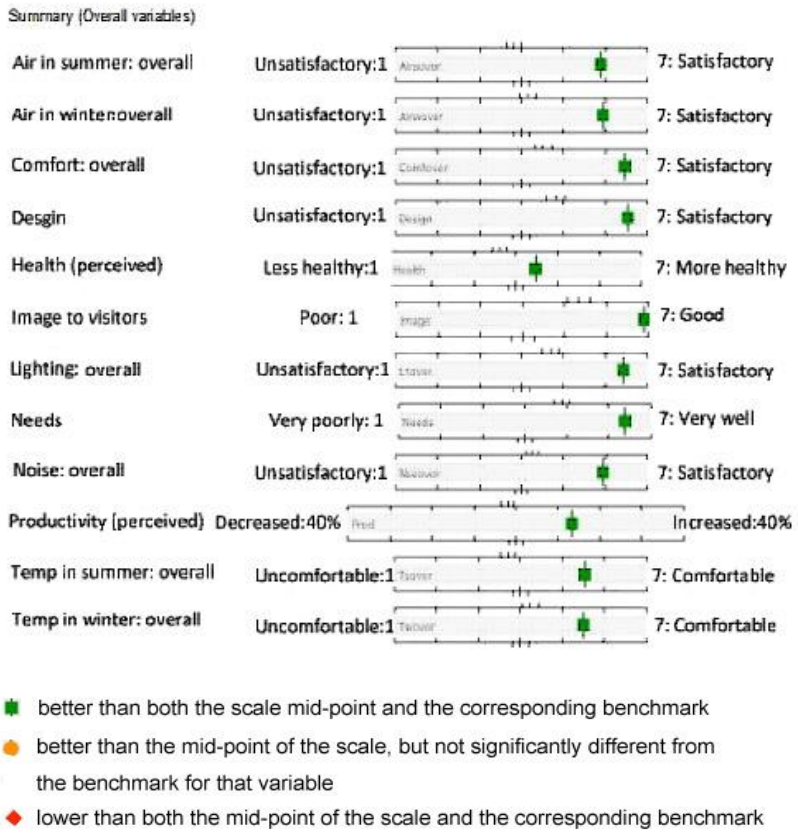


Figure 6.3-1: POE summary of overall variables for St Luke's Primary School (source: Building Use Studies).

Although the POE summary demonstrates a high level of satisfaction among the occupants with the overall building design, some specific issues relevant to the building's indoor environment as well as the building's operational system

in use were revealed through the assessment of a series of precise variables, explained below.

- **Successful factors**
- External appearance, interior design and facilities

The occupants allocated very high scores to the variables of 'Design' and 'Image to visitors', i.e. averagely higher than 6. They commented that the school is a "*beautiful and bright*" environment which is "*inviting*" to both its users and visitors. The interior of the school was also considered to successfully "*provide a lovely working environment*" (Staff, BUS survey, 18 March 2012).

- Flexibility

The design of the multi-functional hub spaces and the flexibility of grouping or separating classrooms were highlighted by the majority of the staff. Some staff considered that the school design provides flexible use of space that is suitable for different curricula. In addition, "*good flow around working areas*" and the shared external playing areas were also commanded by the school staff.

- Sufficient natural light

Majority of the staff thought that the lighting environment in the school was bright to support general teaching and learning activities, although an issue of glare was pointed out by several staff which is discussed in the section of 'existing issues'.

- Needs and controls

In terms of the variable of 'Needs', 92% of the staff believe that the school design has fulfilled their demands and expectations very well. On the other hand, the issue of personal controls over lighting and ventilation was also highlighted by the majority of the school staff, as some staff members believed that "*if the building is sustainably designed, we need to know how to use it in a sustainable way*" (ibid.).

- **Existing issues**
- Glare from the sun and sky

Although the score of the variable 'Overall lighting' is relatively high, the issue of "*too much natural light*" and "*glare from the sun and sky*" was pointed out by the majority of the staff. As interactive whiteboards are generally used in all the learning spaces, glare from low-angle sunlight in winter can easily affect the use of interactive whiteboards in the south-facing classrooms, and in summer the north-facing classrooms sometimes encounter the same problem due to direct sunlight from the northwest.

- Insufficient ventilation in offices

The chief complaints regarding the air quality in the school focused on the issue of "*insufficient ventilation*" in the office spaces rather than in the classrooms. The staff commented that "*ventilation in classrooms is good, but is poor in the offices*" (ibid.). This could be due to the fact that no external window openings are provided.

- Noise from the inside of the school

Although the design of the shared spaces was praised by the staff, the issue of noise from colleagues and students was particularly raised by over 40% of the staff. One staff member commented that "*distraction can happen from others using the same area, such as the activity/cooking area*" (ibid.).

- Insufficient working area

With regard to the working spaces, some staff pointed out that more working spaces for teaching staff need to be provided.

- Higher energy bill than expected

According to the POE analysis carried out by Architype, the issue of the factual energy performance of the school was revealed. The electric usage was higher than hoped, and it was found that the heating continued to operate during the holidays, leading to high energy consumption when the school was empty. In addition, Architype also found that "*there were problems aligning the meter readings taken from the BMS and the mains readings, as the electric and biomass readings were significantly different between the two datasets*" (Architype, 2014).

6.3.3 Summary of POE results

Compared with the BUS benchmark, the survey results regarding the overall design quality of the school are mostly positive, indicating the general success of the school design, particularly in the aspects of appearance, internal spatial arrangement, daylighting and the embodied sustainability awareness. Nevertheless, several issues in terms of glare in classrooms, insufficient

ventilation in offices, and the inappropriate operation of the environmental control system were also reported by the occupants.

6.4 School D

The BUS occupant survey was carried out with the school staff in March 2012, and a short interview with the Deputy Head, Mr R Shield, was conducted during the first visit to the school on 15 March 2012. There are over 100 staff working in the school, but only 25 school staff members responded to the questionnaires. Hence, the POE results may be unrepresentative.

6.4.1 Overall design quality

During the interview with Mr R Shield, he expressed his satisfaction regarding the architectural aspect of the school, particularly the school's external and internal appearance. The flexibility of the school in terms of the spatial usage, such as the design of the central 'heart space', was also praised by Shield;

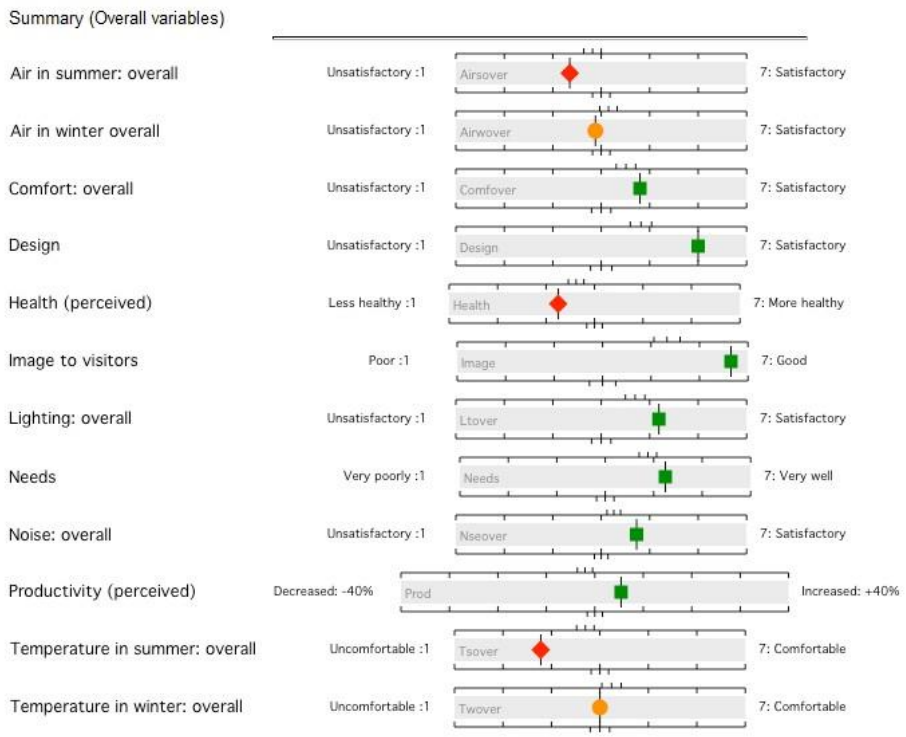
> *The design of the 'heart space' provides some internal and external spaces for various activities, which is quite important for our specialities like music and humanities… It also builds up a good relationship between the school and the nearby community by allowing the community to use some communal spaces after the school hours"* (R Shield, interview, 15 March 2012).

However, several environmental issues related to the quality of the internal environment of the school, particularly the thermal environment in classrooms and staff offices, were pointed out by Shield. Detailed feedback on these issues

is set out in the following section.

6.4.2 Successful factors and existing issues

Although only less than one third of the school staff had been involved in the BUS occupant survey, the participants showed enthusiasm in answering every question in the survey, which generated valuable data. At the time of this study, nearly all the interviewees had been working in the new school building for more than one year, so it can be assumed that their feedback reflects the actual building performance to a certain degree. Figure 4.3-1 shows the summary of the POE feedback for the Minster School regarding some chief variables. Generally, staff were very pleased with the appearance of the building, but some issues related to school environment, comfort and occupant well-being were flagged up (the red diamonds in Figure 4.3-1). Detailed information of the POE results of Minster School can be found in Appendix.



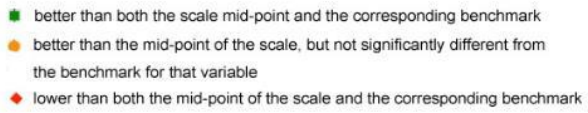


Figure 6.4-1: Minster School's POE summary of overall variables (source: Building Use Studies).

- **Successful factors**
- Overall design and external appearance

The new building's "*modern*" appearance was commended by 92% of the staff. Some staff commented that "*the school looks good from the outside and impressive when you come to the reception area*", and some said that "*it is a really good and modern building to work in*" (Staff, survey, March 2012).

- Spacious and flexible 'heart space'

The majority of the staff liked the design of the 'heart space'; they considered the flexible use of the 'heart space' a clever design feature to maximise the spatial usage, although the noise issue caused by students in circulation after classes/ between classes was raised by some staff.

- **Existing issues**
- Spatial arrangement

Issues related to building layout in terms of spatial arrangement and the particular design for the staff's spaces, like the open-plan office and cellular offices, were referred to positively by most of the staff.

The library located adjacent to the upper part of the 'heart space' was considered as a space that lacked quietness due to the nearby circulation

zone. Noise from students during class breaks and after school hours can easily affect the comfort of those using of the library. Concerning the staff offices, over 90% of the staff thought that the design of the open-plan office, such as the reception office near the 'heart space', offered an inefficient working environment as there are always people passing by and students usually queue outside of the space. Additionally, some of the cellular offices located in the western strip of the school do not have outward-facing windows but, instead, fully rely on electrical light, which does not support a healthy working environment.

- Visual discomfort in classrooms and staff offices

Although the score given by the staff for the overall lighting condition in the school is relatively high, i.e. score of 6, the natural lighting condition in the school was generally commented on as "*variable and insufficient*" (ibid). Forty per cent of the staff pointed out that the level of natural light in classrooms and staff offices was not adequate. Several staff specifically mentioned that their offices do not have windows for natural light which indicates a very poor daylighting design for the staff offices. On the other hand, the issue of visual discomfort due to direct sunlight in classrooms was strongly raised by some teaching staff. One comment that:

> *When the sun is in a certain position, some classrooms are too bright and blinds are too thin to screen out enough light… This glare problem means that pupils find it hard to see the board* (Staff, survey, March 2012).

At the same time, it is noteworthy that more than 40% of the staff raised the issue of too much artificial lighting in the school. "*The lighting in the*

corridors is always on even in the daytime when there are no people passing by", said by Mr R Shield. This could lead to high electricity use; hence greater energy consumption.

- Lack of fresh air and the cold downdraught in winter

In terms of the air quality in the school, the issue of still and stuffy air in classrooms and staff offices was revealed based on the POE results, in both summer and winter times. The poor ventilation was also considered by the staff as the chief reason leading to the overheating problem in some spaces. Another common comment from a number of users was that sometimes the classrooms were uncomfortably cold because of the downdraught of air from the chimneys; this was self-experienced by the author in one of the northwest-facing classrooms on the day of the visit on 15 March 2012.

> *The building is beautifully designed by people who listened to our requirements, and everything we asked for we got. However, we cannot breathe: the kids are hot and stuffy with red faces… It is not so much about the temperature, which is too hot, but I can live with that. It is the lack of airflow and I think the air quality is poor… If I open three doors and a series of manually-operable windows and I stand in one particular spot, I can get some fresh air via a current, but then the windows close by themselves and I cannot stand there all day. In addition, the lights switch themselves off so I have to stand up and walk around to get them back on* (ibid.).

- Thermal discomfort

The majority of the school staff expressed their discontent regarding the variable temperatures in different spaces in the school. They pointed out

that some classrooms are colder than others and some classrooms can be very hot. The overheating problem, particularly in summer months, was considered as the major environmental problem in the school: over 80% of the staff stated that the temperature in some classrooms was too hot to work in. Even with the temperature in the winter months, the issue of variable temperature over the course of a day was also reported by the staff. The thermal discomfort can hugely impact on students' performance and health, as well as the staff's productivity.

6.4.3 Summary of POE results

Compared with the BUS benchmark, the survey results prove the success of the architectural design of the school in terms of its appearance and the interior design. However, a number of environmental issues based on the current design strategies were revealed based on the staff's feedback relating to the quality of the indoor environment of the school - inadequate natural light in classrooms and offices, insufficient fresh air and airflow in both summer and winter, noisy working environment and the overheating problem in classrooms particularly in the summer months. The POE results, to a certain extent, prove the gap existing between the design intents and the actual performance of the school, even though people may have different levels of acceptability of such issues.

6.5 School E

For school E, besides the BUS Occupant questionnaires with the school staff, two extra surveys were carried out in this study. One was using a simplified version of the BUS Occupant questionnaire with a group of school students

aged over 11, and the other was an interview with the site manager that chiefly focused on the practical use of the school and its management system.

6.5.1 Overall design quality

Based on the survey results, head teacher Yarrow was generally satisfied with the overall design quality of the academy, as the scores he gave on most of the design factors were relatively high (i.e. above 6), particularly for the aspect of the relations with the community, the building appearance, and the quality of materials used for construction. Nevertheless, two key issues which he was not quite satisfied with were identified as follows - the spatial arrangement of the school and the use of the sustainable technology employed (i.e. the ground-source heat pump) (Andy Yarrow, interview, 21 March 2012).

> *The design was quite clever for this compact site, and it was sensitive to the local architecture and considered the longer-term impact on the local community… The quality of materials used is unusually good for a school, but it gives the high cost* (ibid).

In terms of the spatial arrangement, the number of classrooms was considered as "*not sufficient*" by the head teacher, and he also pointed out that "*the design of some learning spaces does not match the curriculum*". Besides the classroom arrangement, Yarrow (2012) expressed his opinion that the spaces designed for eating, playing and socialising are limited. "*There is no room for expansion due to the compact nature of the site*", so some open learning spaces designed for group discussion are going to be transformed into classrooms, and additional accommodation off-site would be required to enable future growth (ibid).

With regard to the environmental design of the school, Yarrow highlighted that "*the school is well-insulated and all the classrooms are well sound-proofed*" to avoid interruption of noise from the outside. Nevertheless, he referred to a potential problem regarding the use of the ground-source heat pump; "*the electricity use is quite high and the ground-source heat pump is expensive to maintain*" (ibid).

6.5.2 Successful factors and existing issues

The BUS occupant survey with the school staff was carried out on the first visit to the school in March 2012, and the simplified version of the BUS occupant survey with a group of students was conducted on the second visit to the school in April 2012. In total, 40% of the total staff and 30 students participated in the surveys, respectively.

Before analysing the POE results, two factors need to be brought up - that half of the staff had been at the new school for less than one year, and that the academy was not full to capacity at the time of this study. Thus, the POE results displayed below could be slightly inflated due to the occupant tolerance to some extent, but theoretically the results are reasonable enough to reflect how occupants feel about the design of the school as well as the building in use. In addition, as the number of the students who were engaged in the survey was relatively small, their answers were treated as supplementary information only.

Figure 6.5-1 shows a summary of the feedback from the staff on the chief variables in terms of the architectural design and the quality of the indoor environment of the school. Overall, the school staff expressed satisfaction with

the building design, particularly the aspects of ‘design’, ‘image to visitors’ and ‘needs’. In comparison with the BUS benchmarks, the scores for these aspects are much higher, indicating that the architectural design of the school, such as the appearance and the atmosphere produced has achieved the users’ expectations. Visual comfort in the school seems to be fulfilled as well, but some other environmental factors, such as the air quality and the indoor temperature in summer, were considered as problematic issues by the school staff (see the red diamond in Figure 6.5-1).

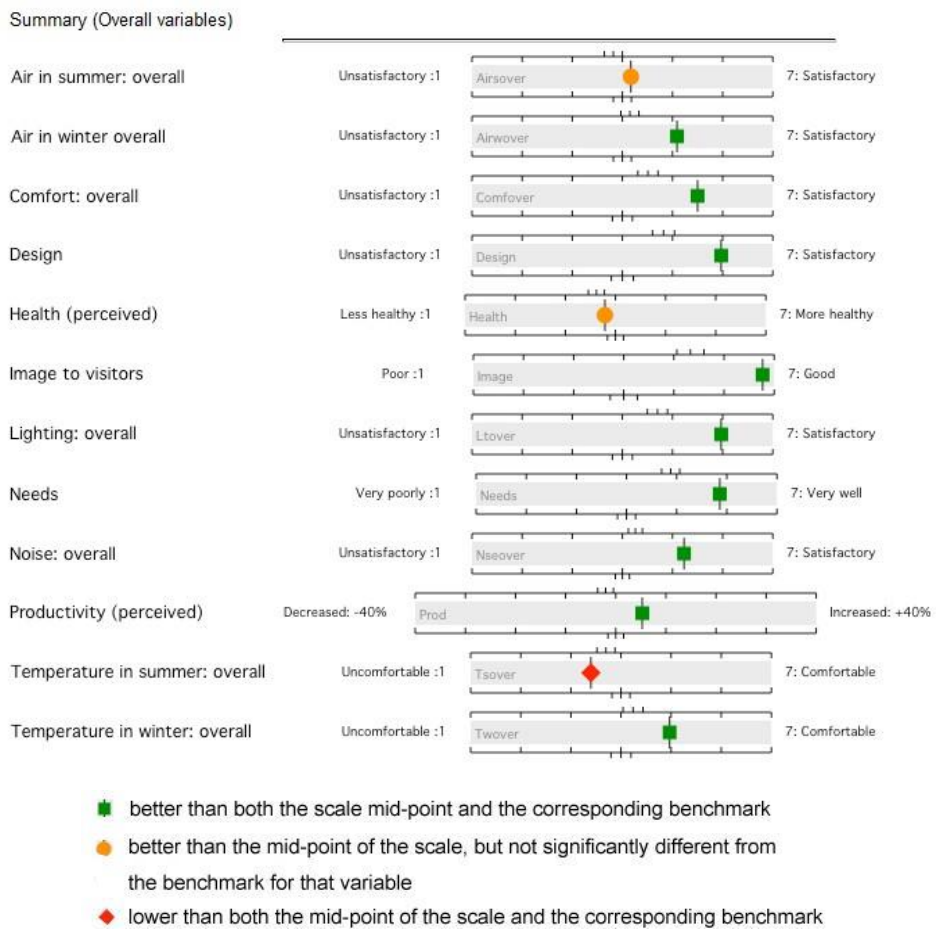


Figure 6.5-1: Chelsea Academy’s POE summary of overall variables (source: Building Use Studies)

- **Successful factors**

- External appearance and overall design quality

The external appearance of the school and the impact of the overall design were considered as "*excellent*" by 83% of the school staff who participated in the survey. A few staff commented that "*the building is very aesthetically pleasing, and it feels nice to work in*".

- Good classroom design and teaching facilities

The majority of the teaching staff commented that the design of the classrooms can fulfill the teaching requirement, as "*bright and spacious*" and well proportioned, and they also expressed satisfaction regarding the furniture, the storage and the computer facilities in the ICT rooms. For general learning spaces, the glazed areas between the classrooms and the corridors were considered as a good design strategy, as this allowed teachers to supervise the internal learning activities.

- Sufficient natural light

Lighting adequacy was highlighted by above 80% of the staff involved in the survey as well as the students, particularly the daylight in the school. They commented that "*the design of the school allows a lot of light to enter the building and therefore to create a sense of space*", and several staff specifically praised the design of the 'light wells' (i.e. central atria in terms of the amount of daylight they admitted. However, it is noteworthy that one member of the site management team expressed dissatisfaction regarding the central atria. He pointed out that "*these atriums do not contribute effectively to improve the lighting environment of the surrounding classrooms but waste of large spaces for this compact building*", and his perspective regarding the effects of the central atria to the improvement of daylighting in the surrounding classrooms, to a certain degree, was

approved in accordance with the evaluation of daylighting performance in Section 5.2.5.

- **Existing issues**

- Limited spaces for offices, dining and recreational activities

Several staff raised the issue that the size of the office space was quite limited. "*Office space for staff is too small, and in particular the support areas out of the classrooms are too small to accommodate both students and staff*", the staff reported. In addition, the issue of no window opening in the office on the ground floor was pointed out. Besides the office space, the inadequacy of the space for dining and recreational activities, such as dancing and playing, was also revealed via the POE results.

> *"The school is good for current capacity, but I am not sure how it will cope with the next year when we have two more year groups… The Academy building provides us a small eating area, and we do not have a space large enough for the whole student body to meet easily. These things were beyond the architect's control, but I think that this is a design flaw, especially the eating area"* (Staff, survey, March 2012).

- Overheating problem in summer and variable indoor temperature

Nearly 70% of the staff raised the issue of thermal discomfort, and commented that the cooling system was "*inefficient*" and hence caused an overheating issue in the summer months. The feedback of the students regarding the indoor temperatures in the school also corresponded to the response of the staff. Beside of the overheating problem, the issues of inadequate fresh air and variable temperatures in different spaces were also

revealed in the POE results. Some students who usually change classrooms in accordance with different curricula commented that "*some classrooms are cold but some rooms are very hot*".

- Controls over ventilation

As the school is primarily controlled by the mechanical system, the windows in most of the key areas cannot be opened in order to minimise the heat loss as well as the energy use. Consequently, manual adjustments over ventilation such as window openings were provided to the occupants – but only on a very limited basis. Based on the POE results in terms of the controls over lighting, ventilation and heating, over 60% of the staff hoped to have more window openings in the school for the admission of more fresh air.

- Noise from the outside traffic and the internal spaces

Although the POE result regarding the overall 'noise' level in the school shows that the acoustic performance of the school is generally good (details can be found in Appendix 3), the noise problem that is due largely to the air conditioning was raised by some staff. "*Sometimes, the air conditioning outside of the classrooms is quite noisy*" (Staff, survey, March 2012).

6.5.3 Summary of the POE results

According to the POE results, they show that the school users including both the staff and the students were generally satisfied with the design of the academy, particularly with the appearance of the school as well as the internal lighting environment. The appearance of the school was commented on by the

head teacher as a success in terms of enhancing the school's identity in the community and assuring a good learning environment, even though this was achieved at great expense.

The achievement of a bright environment was emphasised by the majority of the staff, and the daylighting strategies employed, i.e. the design of the central atria and the fenestration system, received considerable compliments. In particular, the three atria with glazed roofs, which were considered as 'light wells', were highly praised for their ability to introduce daylight to the school as well as to create a sense of space, although the site manager was not convinced by the benefits of this strategy to a certain degree.

Existing issues revealed from the POE results are chiefly related to the spatial arrangement and the indoor thermal environment of the school. The limited space for offices, recreational activities and dining was specifically pointed out by most of the staff, even though the site is too compact to provide a spacious layout. Both the head teacher and the staff thought that the capacity of the school would prove difficult for future growth, as very limited flexibility was provided. Further, the issues of the overheating in summer, variable temperatures in different rooms and inadequate fresh air were pointed out by the staff and the students. It seems that thermal comfort in the school was not fully achieved in both summer and winter. This could be relevant to the school's orientation and be potentially caused by the ineffectiveness of the cooling and heating systems, particularly the air conditioning for cooling. In addition, the air conditioning system was reported by some staff to have a noise issue.

Although some issues relevant to the building performance of the school were

revealed via the POE results, it is noteworthy that some of the survey participants had only occupied the school for less than one year at the time of the study. Consequently, the POE results may be biased or with a certain degree of tolerance regarding the actual building performance.

6.6 Summary of occupant feedback

Based on the previous POE analyses, occupant perceptions regarding the overall environment and design quality of the selected cases was summarised into two indexes – 'comfort' and 'satisfaction', in comparison with the BUS benchmark for non-domestic buildings in the UK. The index of 'comfort' reveals occupant perception towards a building's overall indoor environment that is a combination of lighting, air quality, acoustic and thermal environment. The index of 'satisfaction' stands for the views of occupants regarding a building's overall design and usability, including architectural appearance, functionality and controls.

For school B, satisfaction regarding the school's design and usability and comfort related to the indoor environment was within the BUS benchmark, indicating neutral performance (see Figure 6.6-1 and Figure 6.6-2). The satisfaction regarding the school's architectural design in terms of functionality, appearance, accessibility and security may benefit from the consultations with the client, students, school staff, community representatives, and others, during the design stages. However, several environmental issues related to daylighting sufficiency, air quality in summer and thermal comfort in both summer and winter, as well as usability revealed from the occupant feedback indicate that environmental design of the school was not successful enough.

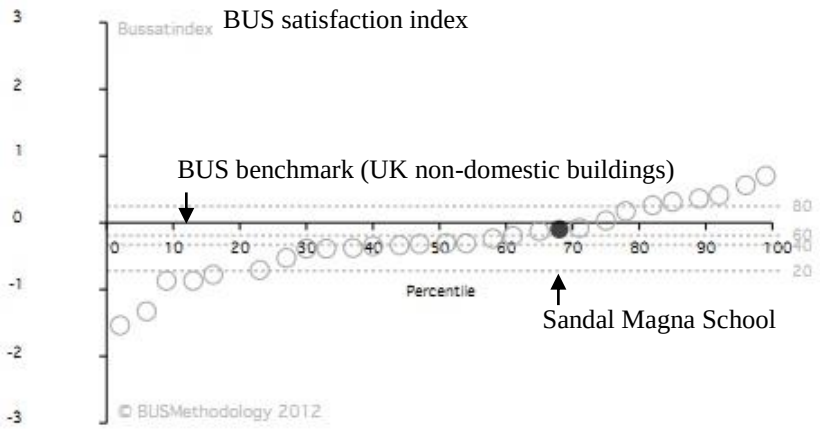


Figure 6.6-1: Satisfaction index regarding the design and the environment of Sandal Magna School (source: Building Usable Studies).

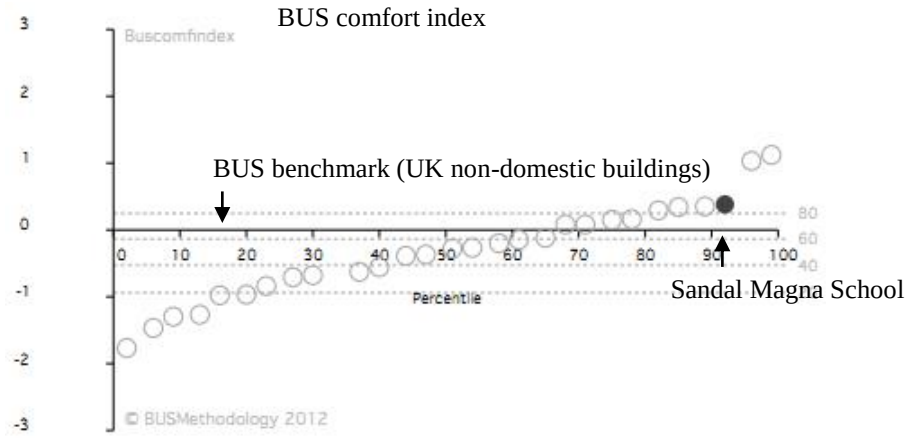


Figure 6.6-2: Comfort index regarding the environment of Sandal Magna School. (source: Building Usable Studies)

For school C, the school users were very pleased with the overall design of the school, particularly the aspects of the school's appearance, flexibility of spatial arrangement and the bright environment. Very high satisfaction index and comfort index regarding the school design and the indoor environment have been attained in the school, compared with the latest BUS benchmark set at the time of this study (2012) (refer to Figure 6.6-3 and Figure 6.6-4). The high values of these two indices indicate that the school design has both met and suited the needs of the occupants and achieved their expectations, in terms of the architectural design and the quality of the indoor environment of the school.

However, specific environmental issues still existed according to the POE results, e.g. the glare problem in classrooms, insufficient ventilation in the office spaces, and noise from the inside of the school.

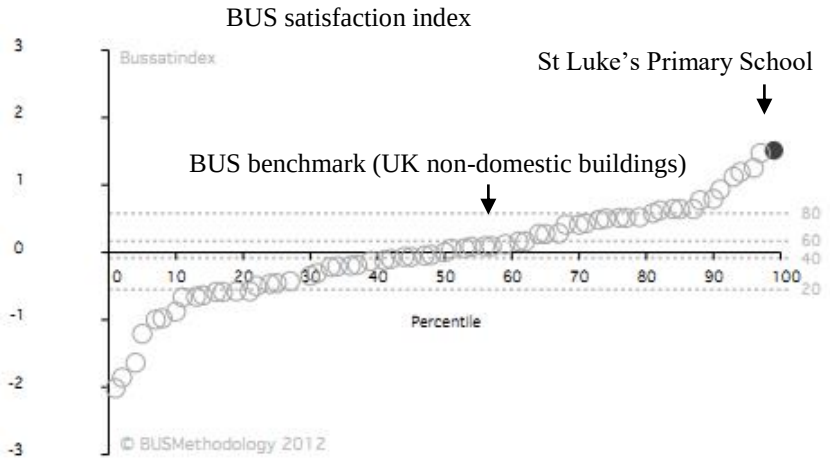


Figure 6.6-3: Satisfaction index regarding the design and the environment of St Luke's Primary School (source: Building Usable Studies).

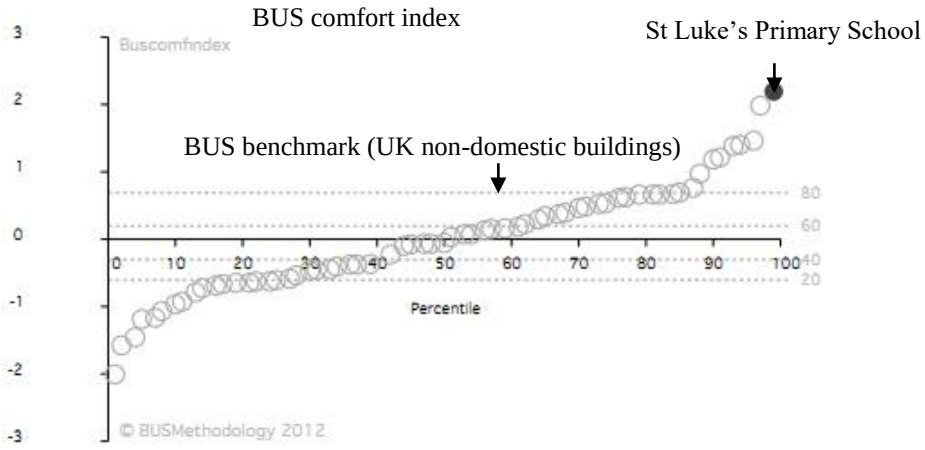


Figure 6.6-4: Comfort index regarding the indoor environment of St Luke's Primary School (source: Building Usable Studies)

With regard to the POE results of School D, overall, a relatively high satisfaction with the school design was identified, compared with the latest BUS benchmark (2012) (refer to Figure 6.6-5). The architectural design of the

school in terms of appearance as well as the design of the central 'heart space' received high praise from the school staff. However, a relatively low level of comfort was revealed related to the school's indoor environment (see Figure 6.6-6 and Figure 4.4-2), and a number of environmental issues occurred, corresponding to the environmental issues found from the school's environmental performance analysis.

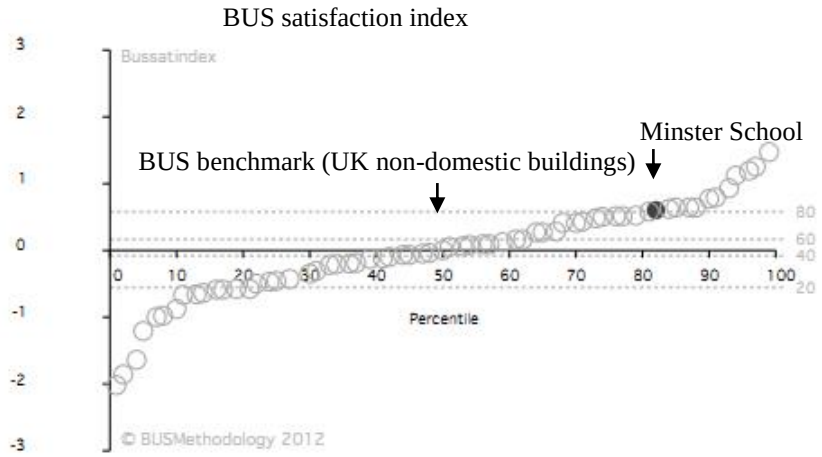


Figure 6.6-5: Satisfaction index regarding the design and the environment of Minster School (source: Building Usable Studies).

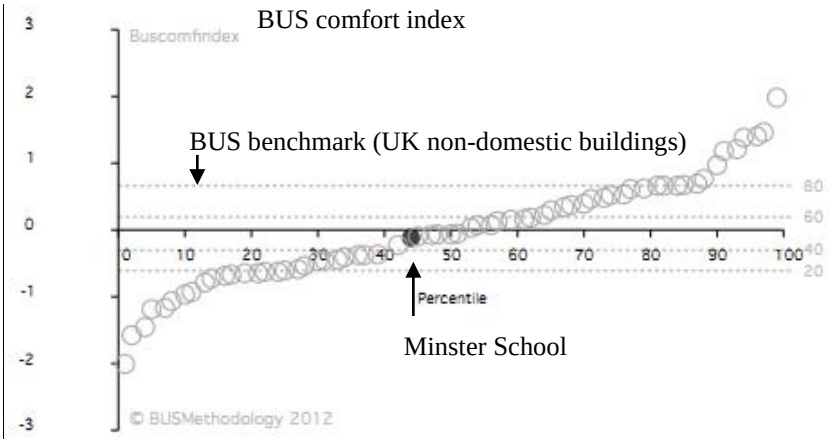


Figure 6.6-6: Comfort index regarding the environment of Minster School (source: Building Usable Studies).

For school E, comparatively high satisfaction index and comfort index have

been attained, compared with the latest BUS benchmark (2011) at the time of this study (see Figure 6.6-7 and Figure 6.6-8). The high value of these two indices implies that the school design has achieved the expectation of the occupants to a large extent; but this could be due to the occupants' high tolerance of the design faults, particularly when they understand that the school design received several awards.

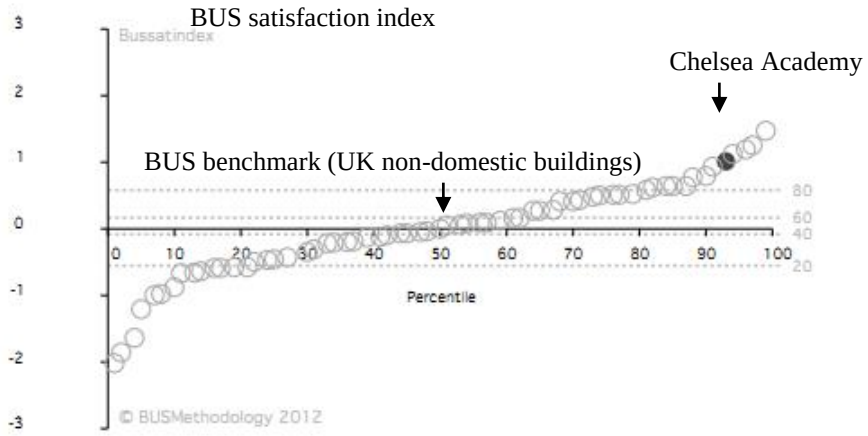


Figure 6.6-7: Satisfaction index regarding the design and the indoor environment of Chelsea Academy (source: Building Use Studies)

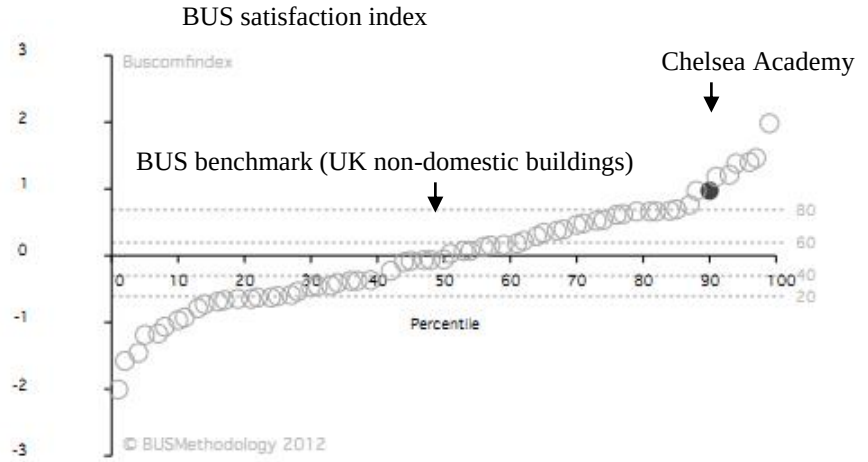


Figure 6.6-8: Comfort index regarding the indoor environment of Chelsea Academy (source: Building Use Studies)

In terms of the architectural aspects of the design, the appearance of the school, the interior atmosphere and the quality of materials utilised were highly appreciated by the school occupants. Majority of the school staff considered that the building was functional and bright. The use of the roof spaces and the basement spaces for recreational activities was particularly highlighted by the head teacher as successful design features for this compact site, even though the issue of lack of flexibility in the spatial usages for future expansion was raised by the school staff and the head teacher.

The site manager expressed his discontent at the design of these atria as "*they take up huge spaces in this compact building and do not benefit the energy consumption of the building*" (Site manager, interview, 12 March 2012). Based on the above discussion, it is difficult to assess whether or not the decision to introduce the atria in this school was the correct one, but it can be inferred from this that any architectural and environmental strategies used for school design should consider the feasibility of strategies based on the local context and site limitations.

- Summary

Learning from the POEs of the five schools studied, in general, occupants show high satisfaction levels regarding the architectural design, indicating that 'design excellence' in terms of building appearance, functionality and spatial arrangement was acknowledged by the school users to a large extent. However, when it comes to the quality of the indoor environment, particularly relating to environmental aspects i.e. lighting environment, air quality, indoor temperature and others, relevant issues were revealed more or less.

Chapter 7 Common issues across the case studies and the influence of design factors

The previous chapters (from Chapter 4 to 6) consist of detailed descriptions and individual analysis of the five case studies, covering mostly technical performance in terms of environmental performance and energy performance of each case, as well as the POE analysis of the building performance in use. The case studies show that building performance of the selected projects branded with 'design excellence' was not as satisfactory as expected, particularly in terms of environmental performance and energy performance. This finding demonstrates the discrepancies between the original design intention and the actual design outcomes, and hence 'performance gaps'.

In the first part of this chapter, overall building performance of the five award-winning schools is summarised and compared with the corresponding benchmarks. Common issues across the case studies emerged, including the gap between the predicted and the actual energy performance, the use of low carbon technologies, daylighting, ventilation, overheating issues, occupant experience regarding use of controls, management and maintenance.

The second part is a brief analysis of the influence of design-related factors on building performance. With the specific aim of addressing objective 3 of this thesis, two key factors impacting on building performance were drawn from the case studies – *design process* and *aftercare service*. In the design process, knowledge and experience of designers as well as design approaches adopted at different stages of the process were found having a great impact on design

outcomes, hence influencing building performance. The level of aftercare service provided by a design team after building completion was also closely related to building performance in practice. The impact of these factors on building performance is discussed in detail in the second part of this chapter, and a model of 'the process' is established, intending to help designers enhance building performance.

7.1 Summary of the case studies

7.1.1 Common issues revealed from the case studies

According to the literatures reviewed in Chapter 2, the model of three principal indicators of 'building performance' is established, illustrated in Figure 7.1-1. The three indicators include *comfort and satisfaction of occupants*, *quality of the indoor environment* in terms of daylight quality, ventilation efficiency and thermal comfort, as well as *operational energy performance*. This model helped the author to evaluate building performance of the schools studied from a synthesis of qualitative and quantitative aspects.

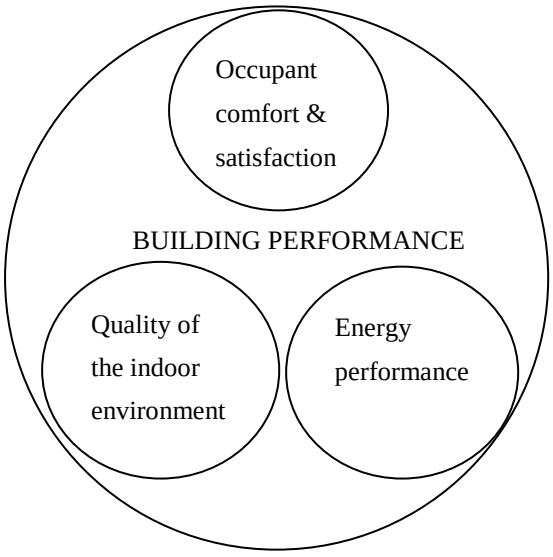


Figure 7.1-1: The model of three principal indicators of building performance (source: Author).

To assess how successful the selected cases, which are branded as exhibiting 'design excellence', are supporting the requirements of end users and contributing to the local environment, building performance of each case in terms of the three aspects mentioned above was evaluated through BUS Occupant survey methodology, environmental monitoring and computerised simulation. The evaluation results were then compared with the relevant benchmarks and environmental standards for educational buildings in the UK.

As per the performance analysis of the case studies, a scoring system that compares the POE results of the five cases studied was established, illustrated in the following figures and tables. In the scoring system, building performance is represented by the symbols of "●", "○" and "▲" that stand for 'satisfactory' performance, 'unsatisfactory' performance and 'neutral' performance, respectively. When the evaluation results are generally better than the corresponding benchmarks or achieve the relevant environmental standards, the symbol of "●" is given indicating 'satisfactory' results; when the evaluation results are mostly lower or worse than the relevant benchmarks, the symbol of "○" is given showing 'unsatisfactory' results. In addition, when the evaluation results are around average, e.g. the POE result is within the range of the BUS benchmarks for general schools in the UK, the symbol "▲" is given, meaning 'neutral' performance.

- Occupant comfort and satisfaction

At the end of each case study, occupant perception regarding the overall environment and design quality of the selected cases was summarised into two indexes – 'comfort' and 'satisfaction', in comparison with the BUS benchmark

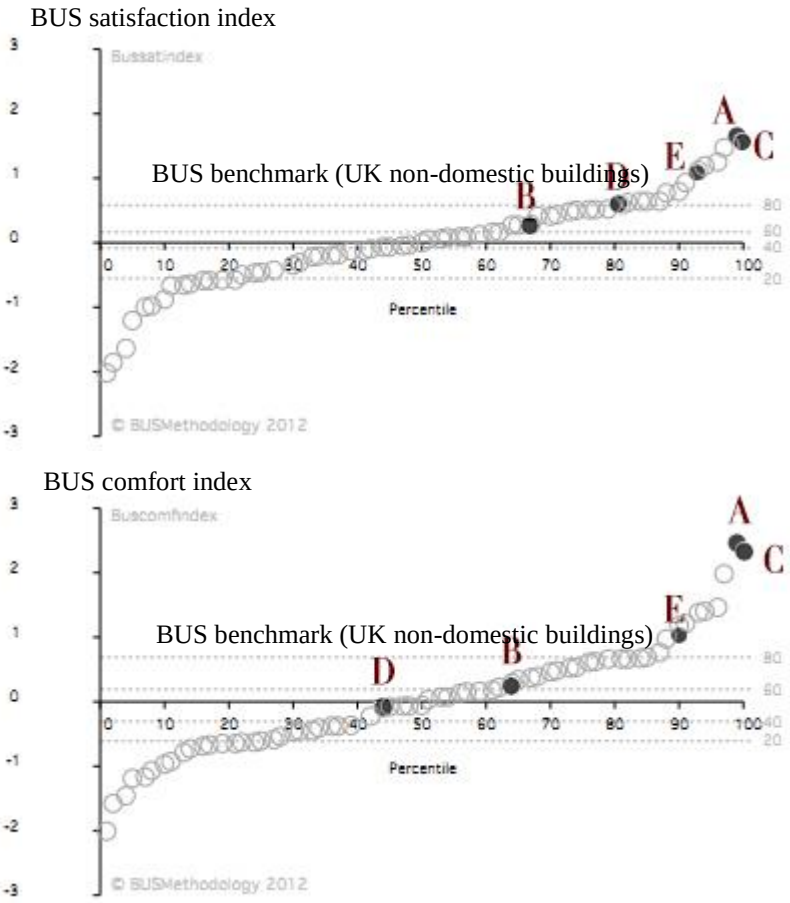
for non-domestic buildings in the UK. These two indexes reflect 'design quality' of buildings from two aspects – the index of 'satisfaction' stands for the views of occupants regarding a building's overall design and usability; the index of 'comfort' reveals occupant perception towards a building's overall indoor environment that is a combination of lighting, air quality, acoustic and thermal environment. The two indexes interrelate to each other, evaluating design quality from both perceptual and physical aspects.

According to the BUS Occupant survey results, the indexes of occupant comfort and satisfaction of all the cases studied are illustrated in Figure 7.1-2, compared with the 2012 BUS benchmark for non-domestic buildings. The results (i.e. locations of the five schools in the benchmark) were calculated by the Building Use Studies on the basis of the questionnaire data collected by the author.

Figure 7.1-2 illustrates that the levels of occupant satisfaction regarding architectural design and usability of School A, C and E studied were higher than the average level of the BUS benchmark generally. For School B and D, the achievement of satisfaction level was within the BUS benchmark. On the basis of the scoring principles explained previously, the symbol of "●" was awarded to School A, C and E in terms of occupant satisfaction regarding school design and usability and hence satisfactory performance, and the symbol of "▲" was given for School B and D indicating neutral performance (see Table 7.1-1).

Referring to the occupant feedback, a majority of the school users involved in the BUS Occupant surveys of this research gave high approval for the 'images' delivered by their schools' appearance, and some staff commented that "*the*

interior atmosphere of the school makes me pleasant" (School staff, interview, 23 February 2012). However, for School B and D, issues related to the school's usability in terms of building operation and the use of environmental technologies and the BMS systems, were pointed out by the site managers. Thus, it is reasonable to infer that although architectural design of the five schools involved in this thesis stood out in 'typical' schools in the UK, usability in terms of school operation and controls was still an issue existing in two of the Award-winning schools studied.



A: Wellstead Primary School; B: Sandal Magna Primary School; C: St Luke's Primary School; D: Minster School; E: Chelsea Academy

Figure 7.1-2: The comfort and satisfaction indexes regarding the indoor environment and design quality, of the five schools studied (source: Building Use Studies and Author).

In terms of occupant comfort, the occupants' comfort level of three schools

studied (i.e. School A, C and E) was above the BUS benchmark (see Figure 7.1-2), implying a relatively comfortable environment perceived by the school users, and hence the symbol of "●" in Table 7.1-1. However, for the other two schools (i.e. School B and D) the symbol of "▲" was awarded, as the comfort level achieved in School B and D was only within the average level of the BUS benchmark. According to the BUS Occupant survey results of School B and D (refer to Chapter 4 and 6), the school users raised several environmental issues, such as insufficient natural light in classrooms, air stuffiness and overheating risk in office spaces, which hugely impacted occupant comfort. The performance analysis suggests that the frequent occurrence of the environmental issues mentioned above was due largely to the inappropriateness of the environmental design applied, such as inadequate daylight source and insufficient air inlets and outlets, and hence discrepancies between the design intention and the actual design outcomes.

Table 7.1-1: Summary of occupant 'comfort' and 'satisfaction' of the cases studied.

Performance indicators \ Case studied		School A	School B	School C	School D	School E
Occupant perception	Comfort	●	▲	●	▲	●
	Satisfaction	●	▲	●	▲	●

A: Wellstead Primary School; B: Sandal Magna Primary School; C: St Luke's Primary School; D: Minster School; E: Chelsea Academy

● – 'satisfactory' performance, ○ – 'unsatisfactory' performance, ▲ – 'neutral' performance

- Indoor environment: daylighting, ventilation and overheating issues

To further evaluate the environmental performance of the selected cases, the three environmental parameters – daylight quality, ventilation efficiency and thermal comfort were analysed specifically through computerised simulation,

on-site monitoring and interviews with the school users. The analysis results are summarised and illustrated in Table 7.1-2 and Table 7.1-3, in comparison with the relevant benchmarks. The case studies suggest that daylighting has been used as a common environmental strategy in all the schools studied with the intention of reducing the use of electrical lights, whereas the daylighting performance achieved in the five cases are various. Table 7.1-2 summarises the achieved daylighting performance of the five schools based on the current daylighting design, in comparison with the latest standards in BDFS 2014.

According to the latest daylighting standards for schools in BDFS 2014, the values of UDI and sDA achieved in all learning spaces should be no less than 80% and 50%, respectively. The performance analysis shows that only the daylighting performance achieved in School A and C reached the standard level, and hence receiving the symbol of "●" in terms of daylighting performance. For the other schools, i.e. School B, D and E, either the achieved values of UDI or the values of sDA are lower than the BDFS standards, indicating the issues of daylight insufficiency or uneven daylight distribution. Thus, the symbol of "○" was given to the daylighting performance of School B, D and E. In addition, the glare risk due to low-angle sunlight was raised by majority of the school staff as a common issue in all the case study schools. The simulation results mostly correspond to the occupant perception regarding the schools' daylight environment. Based on Table 7.1-2, it can be inferred that the daylight design in School A and C, to a large extent, can ensure adequate daylight with balanced daylight distribution in their learning spaces, yet quality daylight was hardly provided in the other three schools studied simply relying on the current daylight design.

Table 7.1-2: Summary of daylighting performance of the cases studied.

Case studied	Classroom orientation	Daylighting performance (Assessment results)			Perceived daylighting performance (POE results)	The in-use daylighting performance
		UDI	DA_{300}	$sDA_{300/50\%}$		
School A	Northwest	87.9%	84.6%	95%	Bright environment with slightly too much natural light; glare from sunlight in winter	●
School B	Northwest	**76.4%**	41.5%	**27%**	Not enough natural light;	○
	Northwest	83%	50.6%	**44%**	(as above)	
School C	North	81%	68.3%	95%	Sufficient natural light	●
	South	81.7%	69.2%	100%	Sufficient natural light; glare from low angle sunlight	
School D	North	83.5%	52.3%	**37%**	Some rooms are bright, but some rooms are dark.	○
	South	**71%**	51.9%	55%	Glare from low-angle sunlight	
School E	West	80%	69.2%	100%	Uneven daylight in different spaces; glare from low-angle sunlight	○
	North	**68.1%**	32.3%	**35.7%**	Insufficient natural light; too much artificial lights	
	North (near atrium)	**75.4%**	44.2%	**44.6%**	The atria create the brightness in the school but did not benefit the surrounding classrooms.	
	South	**71.6%**	47.1%	50.8%	Insufficient natural light; too much artificial lights;	
Baseline design for schools	Typical	≥ 80%	N/A	≥ 50%		

Table 7.1-3: Summary of ventilation and thermal performance of the cases studied.

Case studied	Ventilation efficiency & thermal environment (Assessment results - based on the Optivent calculation and on-site monitoring)	Perceived air quality (POE results)		Perceived thermal comfort (POE results)		The in-use ventilation and thermal performance
		Summer	Winter	Summer	Winter	
School A	Potential risk of being overheated in the classrooms during summer months when the classrooms are fully occupied, due to inadequate air flow rates.	Satisfactory	Still	Hot in some rooms	Comfortable	○
School B	Potential overheating risks in the north-western classrooms due to insufficient ventilation air flow rates; Overheating problem in the south-eastern block due to no shading provided.	Satisfactory	Downdraught	Too hot in staff spaces	Cold in some classrooms	○
School C	Sufficient air movement achieved in summer to remove excessive heat gains in the classrooms, except the north-western classrooms on the first floor due to the current stack height.	Satisfactory but still in offices	Satisfactory	Comfortable	Comfortable	●
School D	Overheating problem in the classrooms when fully occupied, due to insufficient air flow rates; Downdraught issue due to the building orientation and chimney design.	Stuffy	Stuffy; downdraught	Too hot in some classrooms	Temperature variation	○
School E	Evident daily temperature variation; Several south-facing and west-facing classrooms may be overheated when fully occupied; Thermal comfort can be achieved in other spaces generally.	Stuffy	Stuffy	Too hot in some classrooms	Cold in some rooms	▲

Note: A: Wellstead Primary School; B: Sandal Magna Primary School; C: St Luke's Primary School; D: Minster School; E: Chelsea Academy

● – 'satisfactory' performance, ○ – 'unsatisfactory' performance, ▲ – 'neutral' performance

Table 7.1-3 summarises the ventilation and thermal performance achieved in the five schools studied in accordance with the previous performance analysis. The issue of inadequate ventilation and the overheating risk in summer were commonly found in all the schools which use natural ventilation as the primary ventilating strategy apart from School C (i.e. School A, B and D). For School E in which mechanical systems are used as the primary strategy for ventilation and cooling, the issue of temperature variation in different spaces and the overheating risk were revealed based on the occupant feedback. Additionally, for all the cases in which ventilation 'chimneys' were installed for cross ventilation, the occurrence of down draught was pointed out by the school users generally. Based on the synthesis of the performance analysis and the occupant feedback, only School C achieved relatively satisfactory performance in terms of ventilation efficiency and thermal comfort, and hence the symbol of "●" in Table 7.1-3. For the other four cases, the symbol of "○" was given indicating unsatisfactory results, to a large extent.

- Energy performance: 'performance gap', low carbon technologies, management and maintenance

According to the criteria of the RIBA Awards (which can be found in the Introduction in Chapter 1), the factor of 'sustainability' is considered as a chief criterion to judge the quality of the award-entered projects. As a result, it can be assumed that all the cases studied were acknowledged with high energy efficiency and low carbon impact (RIBA 2009). To briefly review how efficiently the energy has been used in the selected cases, the actual energy efficiency of the five schools i.e. the DEC operational rating was compared with the DEC benchmark for typical schools in the UK, illustrated in Figure 7.1-3. In addition, for the schools which have had both the DECs and EPCs at

the time of this study (i.e. School A, B and C), the operational energy efficiency was compared with the favourable asset rating.



School A	EPC		○ 32						▲
	DEC (2010)				● 87				
School B	EPC		○ 38						○
	DEC (2014)					●107			
School C	EPC	○ 24							●
	DEC (2011)			● 68					
School D	EPC								○
	DEC (2012)					●107			
School E	EPC		○ 39						N/A
	DEC								

Figure 7.1-3: Predicted energy performance and operational energy performance of the schools studied (source: Author).

● – 'satisfactory' performance, ○ – 'unsatisfactory' performance, ▲ – 'neutral' performance

Reading from Figure 7.1-3, for School A, B and C which obtained both the EPCs and the DECs, the EPC ratings awarded for these schools at the completion of the design were much higher than the DEC ratings they received after a period of occupancy. It demonstrates that none of these schools performed as energy-efficiently as anticipated, and hence an obvious *credibility gap* between the favourable asset rating and the actual energy efficiency. On

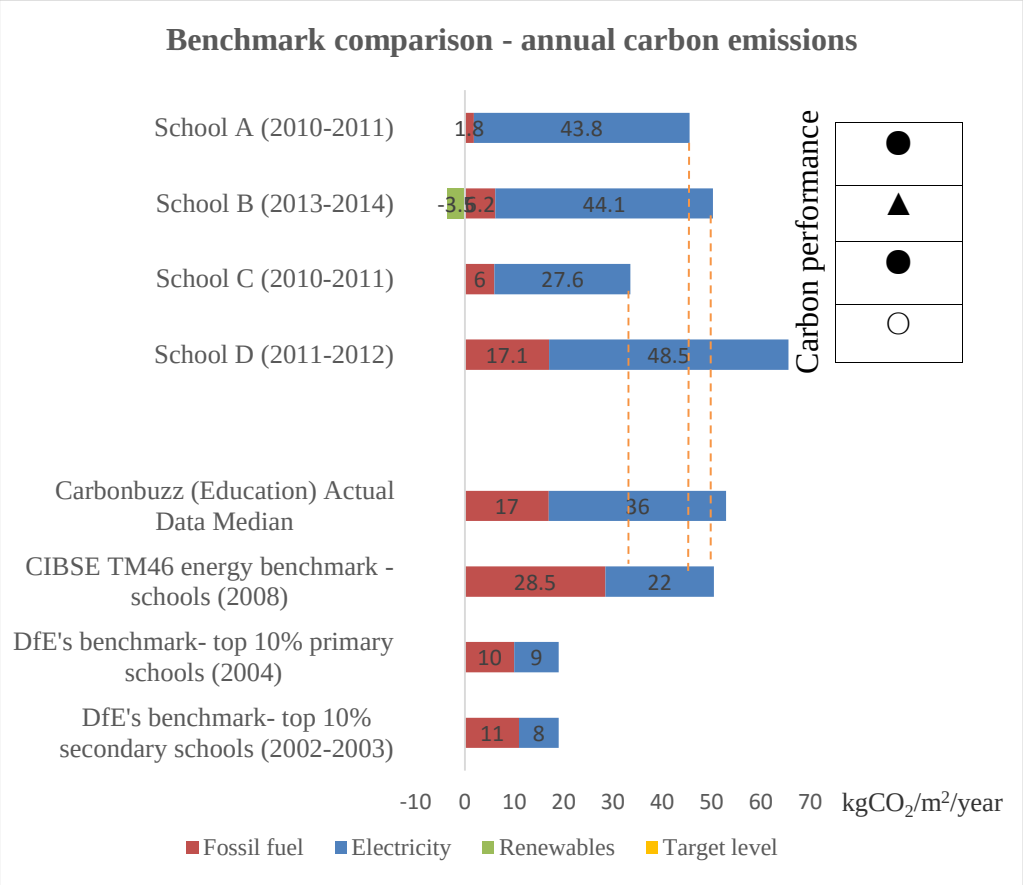
the other hand, only two among the five cases – School A (Rating C at the score of 68) and School C (Rating D at the score of 87) – achieved higher operational ratings compared with the DEC benchmark for typical schools (Rating D at the score of 100), and hence receiving the symbol of "●" in terms of energy performance. For School B and D which the operational ratings were lower than the DEC benchmark for typical schools in the UK, the symbol of "○" was therefore received, indicating energy inefficiency.

It is noteworthy that the absence of the Certificates, particularly DECs, leads to incompletion of the data, thus influencing the credibility of the relevant analysis. For School E which only obtained the EPC but the DEC at the time of this study, its energy performance was not taken accounted into the comparative analysis, because an EPC does not provide information on current energy usage but calculates asset rating. The EPC rating of School E meant potentially high energy efficiency (i.e. Rating B at the score of 39). However, the environmental issues found in the case study of School E (refer to Chapter 7), e.g. daylight inadequacy and the overheating risk in classrooms, would cost much electrical usage for lighting and air-conditioning, and hence potentially high energy consumption. It would be interesting to find out the operational energy performance of School E in comparison with the other schools, as it is the only school which is predominantly controlled by mechanical strategies in the case studies. This step will be completed in the future work. On the other hand, there is a limitation of the work that none of the low carbon technologies were monitored or any analysis of their performance was undertaken which has a significant impact on energy performance. For example, no performance data of heat pumps (co-efficient of performance), biomass boiler or PV panels was shown to prove that they work in reality, as compared to their designed performance and this should be added into future work.

Although the target of "zero carbon" schools by 2019 has been cancelled, another challenging target – 80% carbon reduction by 2050 – has been established to cut energy use in buildings. In addition, Zero Carbon Task Force published by the Department of Education (DfE) in 2010 requires that the annual carbon emissions of new schools should be no more than 10kgCO_2/m^2/yr from 2019. To achieve the Government's targets, a series of passive strategies and environmental technologies were utilised in the schools studied, with the intention of decreasing carbon emissions. Based on the case studies, the annual carbon emissions from electricity and gas of the five cases were illustrated in Figure 7.1-4, in comparison with the relevant benchmarks. The metric – kgCO_2/m^2/yr – has been used to provide the comparison across the schools that describes the amount of carbon dioxide emitted by a building each year divided by floor area. The benchmarks used in the comparison analysis include the DfE's benchmarks for top 10% of schools across the UK, the CIBSE benchmark for schools from Carbonbuzz database and the DEC benchmarks for typical schools in the UK published as CIBSE TM46 (2008).

The current carbon emissions of the five cases are generated from fossil fuel use (presented in red in Figure 7.1-4), electrical usage (presented in blue), and the offset contribution by renewable technologies to neutralise emissions (presented in green). In comparison with the benchmarks and 'traditional' schools in the UK which use fossil fuels as the chief heating source, an opposite trend was found in all the schools studied that more greenhouse gas was produced by electrical usages rather than fossil fuel consumption. This was due largely to the current trend of using 'sustainable' technologies for heating in buildings, such as ground source heat pumps, with the purpose of reducing carbon emissions of buildings. Though the use of environmental or 'zero-

carbon' technologies can increase a building's sustainability credits, the suitability of different technologies may conflict with the building type in some cases.



● – 'satisfactory' performance, ○ – 'unsatisfactory' performance, ▲ – 'neutral' performance

Figure 7.1-4: The annual carbon emissions of the studied schools in comparison with the DfE's benchmarks and DEC benchmarks (source: Author).

Among the four schools involved in the comparative analysis above, School C emitted the least greenhouse gas per year (i.e. 33.6 $kgCO_2/m^2/yr$ in total consisting of 6 $kgCO_2/m^2/yr$ for heating and 27.6 $kgCO_2/m^2/yr$ for electrical consumption), while School D emitted the most carbon emissions per year (i.e. 65.6 $kgCO_2/m^2/yr$ in total consisting of 17.1 $kgCO_2/m^2/yr$ for heating and 48.5 $kgCO_2/m^2/yr$ for electrical usage). In addition, School C emitted the most

greenhouse gas in the three primary schools studied (i.e. School A, B and C). The carbon performance of the schools correspond to the DEC ratings they obtained (see Figure 7.1-3), indicating that School C was the most energy-efficient one while School D performed the least efficiently.

The total annual carbon emissions of all the schools studied (apart from School D) were generally fewer than the CIBSE TM 46 benchmark (2008) for typical schools in the UK (50.5 $kgCO_2/m^2/yr$) and the CIBSE benchmark for the actual data median of the schools from Carbonbuzz database (52.3 kg $CO_2/m^2/yr$), yet remarkably exceeded the DfE's benchmarks for top 10% of schools (19 $kgCO_2/m^2/yr$). To be specific, the annual carbon emissions of School A, B and C were nearly twice more compared with the DfE's benchmark for top 10% of schools, while the annual carbon emissions of School D were three times larger in comparison with the DfE's benchmark for exemplar schools across the UK. Figure 7.1-4 illustrates the large differences between the annual carbon emissions of the schools studied and the government's target. The obvious gap between the design intent – "*low carbon impact*" – and the actual carbon emissions indicates that there is a long way for these 'well-designed' schools to achieve the "low carbon" target based on the current building design.

- Overall building performance

The overall building performance depends on the synthesis of the evaluation results of all performance indicators. Based on the summaries above, the overall building performance of the five cases is condensed in Table 7.1-4 for comparison.

In Table 7.1-4, the overall building performance of the five schools was scored

based on the following rules. For each of the cases studied, if at least one symbol of "●" is awarded for each key performance aspect while the total number of "●" is more than the number of "○", it was assumed that the overall building performance of this case is 'positive' (i.e. '+'), and hence comparatively satisfactory performance in use. On the contrary, if there is not a symbol of "●" awarded for any key performance aspect or the total number of "○" is more than that of "●", the overall building performance was viewed as 'negative' (i.e. '−'), and thus unsatisfactory building performance in use. For School E, based on the occupant feedback (2 "●") and the POE results of environmental performance (1 "○" and 1 "▲"), the building performance was considered as 'neutral', indicating average performance.

According to Table 7.1-4, only two of the five cases achieved comparatively satisfactory performance in practice, i.e. School A designed by HCC Architects and School C designed by Architype. For these two schools, the occupants gave generally positive feedback regarding both the quality of the school's indoor environment and the overall school design, indicating a relatively high levels of occupant comfort and satisfaction. The performance analysis also suggests that the school design, to a large extent, can ensure relatively comfortable environment in terms of daylighting, air quality and thermal comfort, even though several environmental issues related to ventilation efficiency and thermal comfort were found in School A (details can be found in Chapter 4). For the other three cases, i.e. School B, D and E, environmental issues e.g. daylight inadequacy and unevenness, ventilation insufficiency and the overheating problem were revealed in the case studies generally, which not only affected the occupants' comfort but also caused high energy consumption. In addition, the carbon performance of each of the five cases was found far away from the Government's target of 80% reduction of carbon emissions,

particularly the current energy efficiency of School D which was even poorer in comparison with typical schools in the UK.

Table 7.1-4: The comparison of the overall building performance of the five cases studied.

Case studied / Performance indicators		School A	School B	School C	School D	School E
Occupant perception	Comfort	●	▲	●	▲	●
	Satisfaction	●	▲	●	▲	●
Indoor environment	Daylighting	●	○	●	○	○
	Ventilation & thermal	○	○	●	○	▲
Energy performance	Energy efficiency[1]	●	○	●	○	N/A
	Carbon emissions[2]	●	▲	●	○	N/A
Overall building performance in use		5 ● 1 ○	3 ▲ 3 ○	6 ●	2 ▲ 4 ○	2 ● 1 ○ 1 ▲ 2 N/A
		+	−	+	−	Neutral

● indicates that the evaluation results are generally positive, better than the relevant benchmarks or achieve the corresponding environmental standards;

○ indicates that the evaluation results are mostly lower than the relevant benchmarks or do not achieve the corresponding environmental standards.

▲ indicates that the evaluation results are neutral, i.e. within the benchmarks.

All the cases involved in this thesis were awarded for design quality and received at least the BREEAM rating of "Very Good" which indicates a certain

[1] The annual energy consumption compared with the DEC benchmark for UK's typical schools.
[2] The annual carbon emissions compared with the CIBSE TM46 benchmark for schools, i.e. 51 $kgCO_2/m^2$ per year.

level of ‘sustainability’. These buildings are supposed to have both excellently architectural design and equivalently good building performance in use. However, the case studies suggest that not all the selected cases performed as well as expected, particularly in term of in-use environmental performance and operational energy performance, and this is due largely to the inappropriateness of environmental design applied. Discrepancies between the designers’ design intention and the actual design outcomes were demonstrated, and hence ‘*performance gaps*’.

7.1.2 Reasons for the gap between design intent and building performance

According to Bordass et al. (2004), ‘performance gaps’ can be caused by a variety of issues, such as poor briefing, different procurement, limited budget, inappropriate design, construction and commissioning, bad training and wrong maintenance and management, covering from design-related factors to factors with strategic, technical and social natures. With the specific aim of addressing the objective 4 of this thesis, only design-related factors leading to performance gaps are drawn from the case studies and deliberated in the subsequent section, on the basis of the scope of this thesis.

The common design intention of the five schools studied is to provide a comfortable and sustainable learning environment. To achieve this target, a variety of environmental strategies were adopted by the designers to ‘ensure’ building performance, including passive strategies, active strategies and environmental technologies (see Table 7.1-5), whereas the issue of performance gaps summarised from the case studies reflects failure on the relevant strategies employed.

Table 7.1-5: Environmental design strategies used in the schools studied.

	School A	School B	School C	School D	School E
Daylighting	√	√	√	√	√
Natural ventilation	√	√	√	√	
Mechanical ventilation				√	√
Thermal mass		√			
Ground source heat pumps	√	√			√
Under-floor heating	√	√	√	√	√
Biomass boiler			√		
Photovoltaic panels	√	√		√	
Rainwater collection		√			
BMS	√	√	√	√	√

A: Wellstead Primary School; B: Sandal Magna Primary School; C: St Luke's Primary School; D: Minster School; E: Chelsea Academy

Passive strategies Active strategies Environmental technologies Auto-controls

Looking into the environmental design strategies applied to the five cases, passive strategies such as daylighting and natural ventilation and auto-control systems e.g. under-floor heating and BMS have been commonly used in all the five schools apart from School E in which mechanical systems are used predominantly. Environmental technologies like ground source heat pumps and renewable technologies like bio-mass boilers are used in majority of the selected schools (i.e. School A, B,C and E) for heating instead of traditional heating source i.e. gas boilers. However, the performance analysis summarises that only School A and C achieved comparatively satisfactory building performance in practice. A number of environmental issues revealed in School B, D and E suggest that some of the environmental strategies employed did not work effectively in practice, corresponding to the finding of the Innovate UK BPE programme for schools that the use of environmental technologies and

renewable technologies and the use of BMSs were proved having an impact on the performance gap (Innovate UK, 2016).

According to the case studies, *unsuitability of the strategies* and *improper execution* were considered as the chief reasons for performance gaps. A common trend was found in the case studies of School B, D and E in which performance gaps occurred frequently that *in the design process, architects paid more attention to the advancement of the strategies in enhancing a building's 'sustainability credits' but easily disregarded the execution of the strategies as well as the suitability of the strategies for specific building types, i.e. educational buildings in this thesis*.

Taking School B as an example, the most environmental strategies are employed in the school for high level of 'sustainability', consisting of passive strategies and environmental technologies (see Table 7.1-5). However, the performance analysis shows that the least satisfactory building performance was achieved in School B among the five schools (refer to Section Table 7.1-4), indicating a totally opposite results in comparison with the designer's design intention. The case study of School B suggests that the inappropriate execution of daylighting and ventilation design, such as limited daylight source, the absence of shading system, inadequate air inlets and outlets, as well as unsuitable chimney design, largely contribute to the unsatisfactory environmental performance in practice. Similar problems were found in the case of School D and E which building performance was not satisfactory neither (refer to Table 7.1-6). The inappropriate execution of the environmental strategies proposed chiefly resulted in unsatisfactory building performance in use, while the inappropriateness should be found and adjusted by designers during the design process. On the other hand, the use of environmental

technologies, i.e. ground source heat pumps, was about to reduce carbon footprint, yet causing in large part high electrical consumption of School A and B in comparison with the benchmarks (see Figure 7.1-5). This is related to the suitability of using ground source heat pumps in educational buildings, because power consistency is required for this technology to ensure heating efficacy whenever a building is occupied or not and this does not match the feature of educational buildings – temporary occupancy.

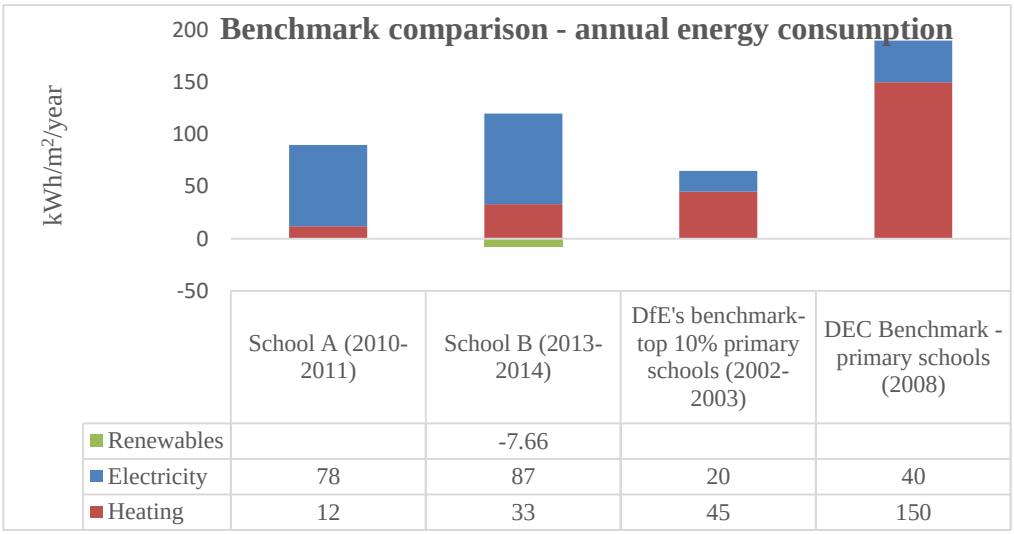


Figure 7.1-5: Annual energy consumption of School A, B in comparison with benchmarks (source: Author).

Table 7.1-6: Inappropriate daylighting and ventilation design in School B, D and E.

	Daylighting design	Ventilation design
School B	 	 Problems： Limited glazing in classrooms due to aesthetic consideration; Internal materials with low reflectivity; Limited air inlets and outlets; Single-oriented chimney design
School D	 	 Problems： Similar window design for classrooms with different orientation; The absence of external shading system ; Limited air inlets and outlets; Single-oriented chimney design
School E		Problems: Limited glazing due to the aesthetic consideration; The absence of external shading system; Mechnical ventilation due to acoustic consideration, which can be addressed via natural ventilation

As per the interviews with the architects involved in the case studies, design decisions related to environmental strategies are determined by architects at the relatively early stages of the design process. Architects decide whether or not a strategy is suitable for the situation in accordance with building type, budget, local built environment as well as demands of end users, based on design experience of architects predominantly (Trebilcock, 2007). For the execution of environmental strategies, it corresponds to the "*analytical process*" defined by Trebilcock (2007) in which members of a design team assess the feasibility of design decisions made at the intuitive stages, through different approaches assisting with analytical tools. This process is deeply reliant on professional knowledge of members of the design team as well as analytical approaches.

The case studies suggest that the design decision-making process and the feasibility-testing process are so important to building performance that both processes deserve great attention of designers. In addition, the case studies indicate that inappropriate building operation and management during the period of building occupancy can result in performance gaps, underlining the responsibility of both building occupiers and designers for aftercare of buildings. These factors were found contributing mostly to building performance, and the impact of these factors to building performance is further discussed in the next section.

7.2 Key factors impacting on building performance

The key factors impacting on building performance are drawn from the case studies and summarised in a model, illustrated in Figure 7.2-1. The model interprets the idea that the factors of *design process*, *construction stage* and *aftercare service* have a tremendous impact on building performance, while

underling the responsibility and commitment of architects from the inception of the design process to the period of building occupancy.

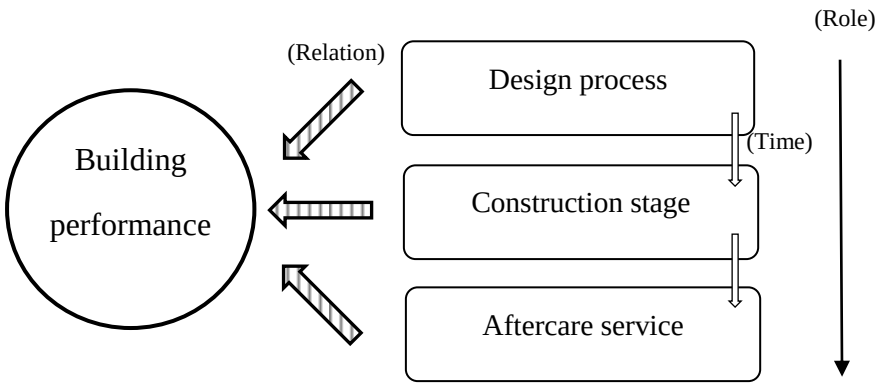


Figure 7.2-1: Key factors impacting on building performance (source: Author).

The design process discussed here is related to the sustainably environmental design process in architectural design. It is normally carried out by both architects and engineers via various design approaches, in order to address different levels of environmental design issues. This process is closely related to knowledge and experience of designers, particularly design knowledge of environmental design issues. Design decisions made during the design process fundamentally determine whether or not a building can perform well in practice.

Transferring to the construction stage, this process controls the practical implementation of design decisions made during the design process, particularly the workmanship issues which can affect building performance (Gupta and Dantsiou, 2013). Nevertheless, this factor was not discussed deliberately in this research on the basis of research feasibility and the scope of this thesis. It is one of the limitations of this research. Further investigation of the workmanship issues impacting on building performance should be carried out in the future work.

After the completion of a project, occupants become the people who use, manage and maintain the building. The propriety of occupant behaviour and operation turns to influence building performance predominantly, whereas the case studies suggest that it is still the responsibility of architects to continue their post-build service, such as training occupants to use their building properly, monitoring building performance in reality, as well as getting feedback from building users and addressing existed problems.

7.2.1 Design process

Rein and Schön (1991) define architectural design as a "*reflective conversation with a unique and uncertain situation*" that architects deal with the uniqueness and uncertainty of the design by managing an interactive process of appreciation, action and re-appreciation. In the case of sustainably environmental design, architects start with understanding the situation through the attempt to adapt to or change it, and then address it through the attempt to comprehend it. Based on this idea, the author divided the design process into two phases – *intuitive stages* and *feasibility stages* (see Figure 7.2-2). The two phases change with time, interrelated with one another.

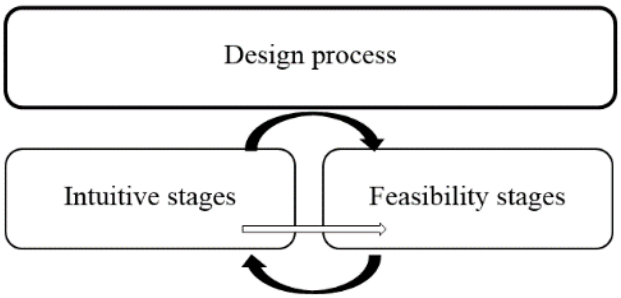


Figure 7.2-2: Two phases of the design process (source: Author).

Architects confront with different levels of environmental design issues at different stages of the design process, while corresponding solutions are also various. The categorisation of the two phases depends on the synthesis of environmental design issues and related design solutions at different stages of the process. At the intuitive stages, initial design decisions related to environmental design issues are relatively fundamental and architectural, such as sites, orientation, built form, fabric and exposure, fenestration and shading system. To cope with these issues, architects normally rely on an "*intuitive process*" based on knowledge and experience of members of the design team primarily (Trebilcock, 2007).

> *"The intuitive process plays an important role throughout the design process but it is more essential during early stages of the process… It guides early and fundamental design decisions"* (Trebilcock, 2007, p. 264).

At the feasibility stages, designers encounter environmental design issues that are somewhat specific and technical, related to detailed strategies of lighting, ventilation, heating and cooling systems. Feasibility of the design decisions proposed at the intuitive stages is required to be assessed to ensure building performance. To achieve this target, '*evidence-based design'* (EBD) (Claridge and Fabian, 2005; Hamilton and Watkins, 2009) that is a process to develop appropriate design decisions on the basis of evidence gathered from the design process is predominant at this phase, fundamentally guided by the use of design assisting tools to update and check previous design decisions. Knowledge acquired from education and research can be supportive at this phase as well.

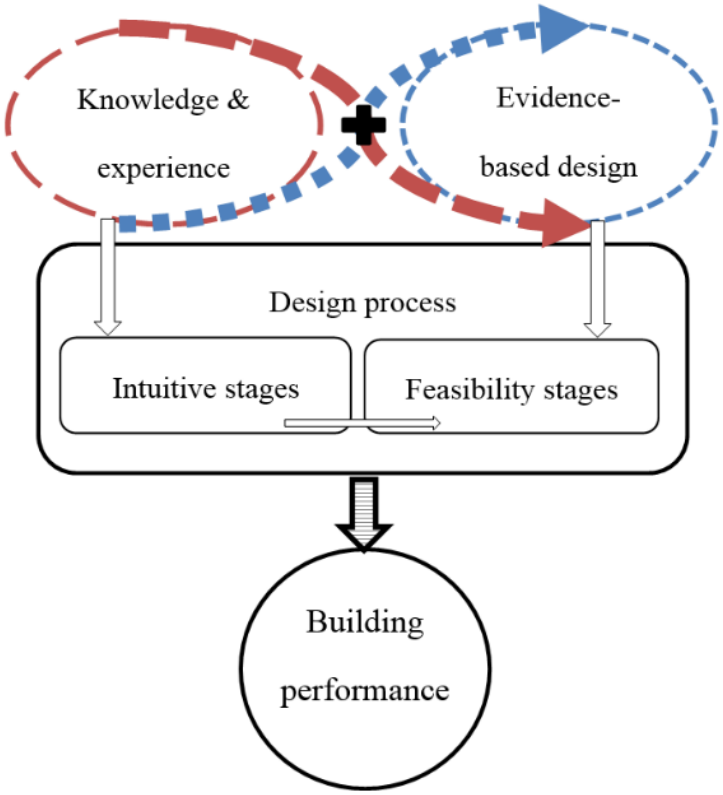


Figure 7.2-3: Key factors impacting on building performance during the design process (source: Author).

The essentials contributing to the design process are summarised in Figure 7.2-3 – *knowledge and experience of architects* and *evidence-based design approach*. Knowledge and experience of architects play an essential role throughout the whole design process, but provide more contribution at the intuitive stages. On the other hand, evidence-based design approach helps designers make proper design decisions from the inception to the late stages of the design process, but offers supportive evidence more frequently at the feasibility stages. The case studies suggest that both factors contribute to the design decision-making process, thus influencing design outcomes. The impact of the two factors on building performance changes with time – the influence of designers' knowledge and experience decreases from the intuitive stages to the feasibility stages, while the function of evidence-based design approach increasing with design progress (see Figure 7.2-3).

- Knowledge and experience vs. building performance

In architectural design, knowledge and experience are closely interrelated. Architects normally face a design project with a store of knowledge about what has lead up to it (Peach 1990, p.51). According to Williamson et al. (2003), the knowledge of architects about what is to be 'true' or 'correct' regarding environmental and other aspects of sustainability in architectural design is deeply reliant on the architects' experiences of, and ideas about, environmental issues, buildings, the role of architects and the nature of design (Williamson et al., 2003, p. 67).

Design knowledge that is acquired over time and rooted in experience was conceptualised as "*tacit knowledge*" by Polanyi in 1967. This type of knowledge is considered having a profound influence on architects at the early stages of the design process, thus guiding early design decisions (Trebilcock, 2007). On the opposite to tacit knowledge, it is "explicit knowledge" that relates to academic and theoretical knowledge, rooted in research (Bouwen et al., 1999). This type of knowledge is usually gained from colleges or research conducted by designers. According to Trebilcock (2007), both tacit knowledge and explicit knowledge have a great impact on the success of sustainably architectural design. Thus, it is rational to infer that architects who have much experience and professional knowledge regarding sustainably environmental design have more opportunities to deliver buildings with better performance.

All the architectural practices involved in the case studies of this thesis have been established for a relatively long periods and have designed a large number of projects (see Table 7.2-1). More importantly, these five practices are with

high reputation for sustainably architectural design in the profession.

Table 7.2-1: Experience of the five architectural practices vs. building performance of the selected cases.

Architectural practice	Knowledge and experience			Case designed and the corresponding performance	
	Design experience	Projects	RIBA & Sustainability award-winning projects		
HCC Architects	>30 years	500+	19	School A	+
SWA	>20 years	100+	6	School B	−
Architype	>30 years	500+	18	School C	+
P&P	>25 years	300+	21	School D	−
FCBs	>35 years	500+	> 50	School E	Neutral

Learning from the interviews with the architects involved in this research project, HCC Architects have acted as the pioneering in design of public sector properties for over 30 years. Most of their work has been considered as the integration of "*quality and value in the built environment*" (Macmillan, 2004). Over the last 30 years, HCC Architects have won 19 RIBA Awards because of design excellence and sustainable consideration of their work. According to the interviews with the lead architect of School A, today a number of school projects delivered by HCC Architects, such as Wellstead Primary School, Endeavour Primary School and Burnham Copse Primary School, which won both architectural- and sustainability-related awards, were still designed to learn from the tradition of 'Hampshire schools[1]' while using new architectural languages (Presley, interview, 19 February, 2012). 'Tacit knowledge' gained from experience and prior work, therefore, plays an essential role in their

[1] Hampshire schools are well known as exemplars of good school design, which integrate the environmental function of buildings into architectural design mutually (Weston, 1991).

design process.

Architype was the first architectural practice in the UK that conducts Passivhaus approach in architectural design, and designed one of the first three primary schools in the UK which received Passivhaus certification successfully (i.e. Oak Meadow Primary School). Since its set up, awards won include Sustainable Architect of the Year 2007, Green Business of the Year 2008, BCSE School Architect of the Year 2011, and a number of RIBA Design Awards. According to the interview with one of the chief architects of School C interviewed in this research project, the design purpose of Architype is to "*design life enhancing, genuinely sustainable architecture*" (Mikurcik, interview, 14 March 2012). BIM (Building Information Modelling) and 'Soft Landings' approach have been undertaken by Architype in their projects to "*ensure the buildings perform as they should*" (Architype, 2014), implying the execution of an integrated process.

P&P has been voted as AJ100's 'Sustainable Architect of the Year' 2014 winner (AJ 2014). With high reputation in sustainable design, they have won over 20 RIBA Awards and Sustainability awards. In addition, they are the participants in the Carbon Buzz research projects, and have worked with the academics from Oxford Brooke's University to undertake regular (2004 – ongoing) POEs of their projects, with the purpose of enhancing their 'explicit knowledge'.

For FCBs with over 35-year design experience, they have been recognised as "*pioneering environmental expertise*" in the profession and confirmed as "*leaders in sustainable design*" by BRE (2015). Since its establishment, FCBs have won the most RIBA awards in the UK (i.e. over 50 RIBA Awards). According to the interview with Clegg, FCBs have undertaken a series of

research projects related to sustainable design, such as POEs of environmental performance of schools and the research regarding embodied energy and materials with the University of Bath (Clegg, interview, 14 February, 2014). These research projects are capable to enhance both tacit and explicit knowledge of the design teams.

For SWA set up by Sarah Wigglesworth in 1990s, it is a comparatively smaller design company compared to the other four architectural practices involved in this thesis. SWA believe that "*good design in all its aspects can improve our wellbeing and make things work more efficiently and economically*" (SWA, 2012). Since its establishment, 6 RIBA Awards have been received. Wigglesworth interviewed claimed that research in terms of POEs of their projects has been ongoing although sometimes the funding is too limited to support this kind of research (Wigglesworth, interview, October 2012).

According to Lawson (2004) and Trebilcock (2007), the design knowledge and experience of the designers from the five architectural practices should be supportive to delivering quality architecture with good building performance. Referring to the previous performance analysis, building performance of the two cases studied achieved the satisfactory level (i.e. School A designed by HCC Architects and School C designed by Architype), corresponding to the above assumption. However, building performance of School B, D and E did not reach the anticipated level, contrasting with the above assumption. According to the reasons for performance gaps summarised in Section 7.1.2 (i.e. unsuitable strategies and improper execution of strategies), it is reasonable to infer that considerable knowledge acquired from both experience and research is essential for architects to make proper design decisions at the relatively early stages of the design process but cannot ensure the achievement

of good building performance for some other reasons. In other words, how to assure the effectiveness of design decisions made at the intuitive stages is vital to final design outcomes, hence affecting building performance.

- Evidence-based design vs. building performance

Based on the analysis in Section 7.1.2, design decisions proposed at the intuitive stages should be further checked and adjusted by architects at the feasibility stages, in order to assure that design outcomes i.e. building performance are consistent with design anticipation. The importance of proper design approaches in the design process is evidently clear.

Derived from "*evidence-based design*" (EBD) for healthcare facilities (Sackett, et al., 1996), EBD in architectural design means a process that designers make design decisions based on the information available from research, project evaluations, as well as information and evidence gathered from other sources, like requirement of clients and end users. In architectural design, the decision-making process is relatively complex. Design decisions cannot simply depend on cause-and-effect predictions, but are required a comprehensive understanding towards the function of architecture in terms of variable components, such as form and construction, lighting, ventilation and thermal systems, and their relationships (Hamilton and Watkins, 2009). EBD is a common approach used throughout the architectural design process, while specific methods of EBD conducted by architects at different stages of the design process are various. In the case of sustainably environmental design in architecture, approaches of EBD normally depend on characteristics of environmental design issues that need to be addressed at different phases.

At the early stages of the process, EBD is about to collect useful information for guiding the early decision-making process. The useful information at the inception of the design process involves site opportunities and constraints, climate at local environment, as well as specific demands and requirement of clients and end users. Based on the interviews with the architects involved in the cases studies, EBD at the inception of the design process was carried out by the design teams, normally architects. Detailed methods included background research, precedent studies, site analysis, micro-climatic analysis and consultation with clients and end users. General site analysis, simply micro-climatic analysis and consultation with clients or school users were carried out by all the five design teams, yet only the design teams from HCC Architects, Architype and FCBs conducted precedent studies at the pre-design stages. By carrying out precedent studies, architects learnt from the past, referencing both advantages and limitations of the previous works related to school design (Presley, et al., interviews, 2012).

Referring to the building performance of the selected schools designed by HCC Architects, Architype and FCBs, School A, C and E achieved better building performance in comparison with the other two cases (School B and D) in which precedent studies were not conducted at the early design stages (see Table 7.2-2). As tacit knowledge gained from experience is embedded in designers and actually drive the early stages of the process (Trebilcock, 2007), it is reasonable to infer that EBD at the intuitive stages, particularly prior studies, has a constructive guidance for early design decisions. It allows architects to deal with new issues via utilising experiential knowledge in a systematic manner.

Table 7.2-2: EBD conducted at early stages of the design process, and building performance.

Architectural practice	EBD at early stages of the design process				Case designed and the corresponding performance	
	Site analysis	Micro-climatic analysis	Consultations	Precedent studies		
HCC Architects	√	√	√	√	School A	+
SWA	√	√	√	×	School B	−
Architype	√	√	√	√	School C	+
P&P	√	√	√	×	School D	−
FCBs	√	√	√	√	School E	Neutral

At the feasibility stages, architects face an increasing number of technical challenges that require more sophisticated skills to deal with. The EBD at this phase particularly refers to the "*analytical process*" defined by Treblicock (2007) that it concerns the use of design-assisting tools to guide, analyse and evaluate sustainable design decisions. Additionally, as per the interactive process of "*appreciation, action and re-appreciation*" (Rein and Schön, 1991), what architects do after the analytical process, like adjusting and refining design decisions, is part of the EBD at the feasibility stages. Methods of EBD at the feasibility stages are normally recognised as *performance prediction analysis* that is, to predict building performance based on the design decisions proposed at the intuitive stages, conducted by expertise of the design team. In the analytical process, the expertise can be architects, in-house engineers or engineers from the third parties, and the design assisting tools can be paper-based e.g. analytical sketches and simple calculation, computer-based e.g. simulation programme for building performance, or physical tools e.g. physical

models and artificial sky. Besides performance predictions, energy predictions and specifications should also be involved.

According to the architects interviewed, performance prediction analysis was generally carried out in the design process of all the cases studied, and was predominantly executed via computer-based tools. It covered the performance prediction of the chief environmental aspects: daylighting, ventilation and thermal environment. It is noteworthy that the analytical process for the five cases was mainly executed by engineers from the third parties with excellent reputation for environmental consultancy, such as Max Fordham and Buro Happold, rather than architects themselves. Based on the purpose of EBD, it is reasonable to assume that design decisions refined based on performance prediction analysis should be able to deliver satisfactory design outcomes, i.e. good building performance. However, the previous performance analysis shows that some cases studied did not perform well in practice (refer to Table 7.1-4), even though performance prediction analysis was carried out at the feasibility stages of all the cases studied.

The case studies suggest that the issues of *doubtful approaches used in performance prediction analysis* and *inaccurate refinement and modification to design decisions* are the chief reasons for the conflicts mentioned above. For all the five cases, the prediction analysis regarding daylighting performance was carried out by the design teams via the "*conventional daylight factor approach*" (Nabil and Mardaljevic, 2006, p. 905). The limitation of this approach has been proved by Nabil and Mardaljevic (2005) that it only provides simulation results under the overcast sky condition but ignores realistic, time-varying sky and sun conditions. In the case studies, the author conducted the climate-based daylight analysis (i.e. UDI approach) when evaluating daylighting performance of the

selected schools. The UDI approach which offers climate-based analyses of daylight illuminance levels that are grounded on hourly meteorological data for a period of a full year should be able to provide more accurate and realistic results in comparison with the DF approach.

Table 7.2-3: Comparison of expected, perceived and evaluated daylighting performance of the five cases.

Expected daylighting performance *Based on DF approach + design modification* (design team)	Perceived daylighting performance *Using BUS Occupant survey* (school staff)	Evaluated daylighting performance *Using climate-based daylight anslysis* (author)	Case
●	○ *"Bright but too much natural light and glare"*	● *But with glare risk*	School A
●	○ *"Too little natural light"*	○ *Insufficient natural light*	School B
●	● *"Bright"*	● *Sufficient and even daylight*	School C
●	○ *"Too little natural light and glare"*	○ *Insufficient daylight and glare risk*	School D
●	▲ *"Uneven daylight"*	○ *Insufficient daylight and uneven daylight distribution*	School E

●: Satisfactory, ○: Unsatisfactory, ▲: Neutral, ●: Expected to be satisfactory

Table 7.2-3 shows a comparison between the author's evaluation results regarding daylighting performance of the selected schools via climate-based daylight analysis and the POE results of the school users' perception regarding

daylight quality of their schools. Although there is a slight difference between the two results, an obvious consistency can be found between the author's evaluation results and the school users' perceptions. This implies that the simulation approach used by the author, to a large extent, is effective to produce convincing and meaningful results. At the same time, Table 7.2-3 displays another comparison between the school users' feedback and the expected daylighting performance of the five schools. It is reasonable to assume that the expected daylighting performance of the five schools should be 'satisfactory' after the design modification based on the performance prediction analysis (via DF approach). However, the case studies suggest that the daylighting design of School B, D and E was not effective enough to provide quality daylight, and this should not occur if the EBD conducted at the feasibility stages worked effectively. On the basis of the above findings, it can be inferred that the unsatisfactory daylighting performance of the schools studied could be caused by two issues – *doubtful approaches* used in the performance prediction analysis or *ineffective design refinement* based on the prediction analysis using doubtful approaches.

According to the action of "re-appreciation" (Rein and Schön, 1991), not only the analytical process has a great impact on the correctness of design decisions, but also design refinement and modification carried out after performance prediction analysis. This re-appreciation process helps architects gain experiential knowledge from both design correctness and design mistakes, especially contributing to building performance. Referring to the case study of School C which achieved the most satisfactory building performance among the five cases, architects from Architype polished a series of early design decisions based on the performance prediction analysis conducted by Buro Happold, such as size and location of windows in the south-facing classrooms,

size of skylights for a the south-facing classrooms, as well as chimney height for the north-facing classrooms. As a result, satisfactory building performance in terms of daylighting, ventilation and thermal performance was generally achieved in School C. On the contrary, for School B and D whose building performance achieved was unsatisfactory, few refinement was made at the late stages of the design process if compared to the design decisions proposed at the middle design stages. It can be, therefore, inferred that whether or not designers carry out proper modification to the early design decisions at the feasibility stages has a great impact on building performance.

- Suggestions

As such, both design knowledge and design approaches (i.e. EBD) play an essential role in determining building performance in the design process. Architects are, therefore, required to enrich their design knowledge and design skills, particularly regarding environmental design issues, and to be involved in the EBD process as frequently as possible. Regarding the methods of enhancing design knowledge and skills of architects in terms of sustainably environmental design in architecture, the author proposed a series of suggestions towards how to embody these information into a design module. As it is not within the scope of this research project, the proposal is located in Appendix 4 for future reference.

7.2.2 Aftercare service

As mentioned previously, occupiers turn to the people who master and operate a building once it has been handed over. Occupant behaviour, operation, maintenance and management have a direct influence on the design outcomes in practice, i.e. operational building performance. There is a common

phenomenon that designers are normally employed to deliver or to alter buildings and go away as soon as the project is physically complete and handed over (Adamson and Bordass, 2004). Building users and management are, therefore, hardly to learn how to operate, maintain and manage their buildings properly. This phenomenon can result in performance gaps easily.

According to the 'Soft Landings' Framework published by BSRIA in 2014, the aftercare service that covers from providing support, detecting problems, undertaking fine-tuning to long-term monitoring, POEs and reviews can largely contribute to ensuring that sustainable strategies work in practice, hence improving building performance. On the other hand, it provides designers a learning opportunity to gain useful experience from their own works and to set up design database for future reference.

> *"Architects are seldom asked or paid to follow-through afterwards, to pass on their knowledge to occupiers and management, or to learn from the interaction. Consequently, the industry does not unlock all the value in the buildings it creates. Nor does it fully understand what it is creating, what works well, and what needs to be improved"* (BSRIA, 2014, p.10).

Table 7.2-4 describes the potential relationship between the aftercare service adopted for the five cases and the corresponding building performance, particularly for operational energy efficiency. It is not difficult to find out that more aftercare service has been carried out after the completion of buildings, and better building performance, particularly higher energy efficiency, was achieved in practice. Among the five cases studied, the most aftercare service has been applied to School C which achieved the most satisfactory building

performance and highest energy efficiency. On the contrary, the least aftercare service has been carried out for School B and D in which performance gaps occurred frequently.

Table 7.2-4: Post-build service conducted by the five architectural practices involved in the thesis.

Architectural practice	Aftercare service			Case and the corresponding performance	DEC ratings
	Review of commissioning of services and systems	Training and guiding occupants	On-site monitoring and POE		
HCC Architects	√	✓		School A +	Rating D(87)
SWA	√			School B −	Rating E(107)
Architype	√	√	√	School C +	Rating C(67)
P&P	√	✓		School D −	Rating E(107)
FCBs	√	√		School E Neutral	N/A

According to the interviews with the architect from Architype who managed the design of School C, the aftercare service applied to the school included the review of commissioning of building services (i.e. providing 'environmental guidance' in classrooms informing environmental features of the school), training facility management, collecting feedback and a POE study (i.e. assessing building performance and then mentoring school staff to operate the school properly). In addition, problems such as high electrical usage because of improper building operation were revealed in the reviewing and POE process (Mickurcik, interview, 14 March 2012). Relevant solutions were offered by the design team immediately after the POE when architects of the design team

mentored the school staff to habitually switch off electrical lights and computers when there are no necessary demands. Referring to the energy performance of School C, the best DEC rating was achieved in comparison with the other cases studied (i.e. Rating C at the score of 67), indicating the positive influence of post-build service to building performance. Nevertheless, there were still gaps between the expected energy performance and the operational energy efficiency (refer to Figure 7.1-3), and this may be caused by over-optimised anticipation or other issues related to construction.

For the other cases studied, aftercare service was more or less conducted by the design teams, but the aftercare period of the two schools with unsatisfactory building performance (i.e. School B and D) was relatively short (see Table 7.2-4). It is reasonable to infer that aftercare service cannot be executed as a one-off product provided by designers. Instead, it should cover a relatively long aftercare period, providing frequent actions and visits at the initial handover stage and periodic reviews once the initial aftercare is over. A systematic routine of aftercare service was, therefore, set up to guide the aftercare of buildings properly. Based on the 'Soft Landings' Framework (2014), aftercare service can be executed through a three-phase process, comprising the pre-handover stage, the initial aftercare and the extended aftercare (see Figure 7.2-4).

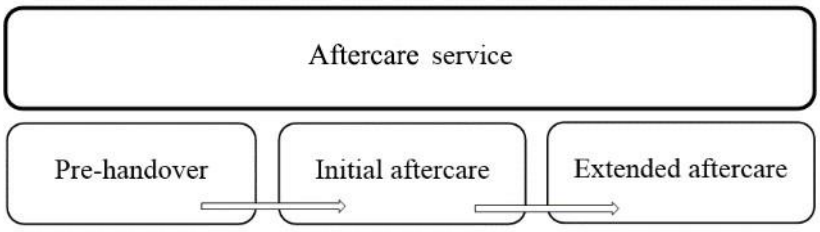


Figure 7.2-4: Three stages of post-build service (source: Author).

At the pre-handover stage, it is about to ensure to deliver a building that is ready for use. Designers should check the static function of a building, such as inspections of airtightness details, window opening devices and linkages, and envelope pressure tests. Environmental systems employed need to be checked as well, like natural ventilation, renewable energy systems, metering installations and effective user interfaces, among many others.

During the initial aftercare period, the service is intended to help building users to understand their buildings as well as to support facilities managers to operate building systems. Sufficient guidance should be provided by the design team in order to avoid the occurrence of unpleasant 'surprises' in use. Taking School A and B as examples, the facilities managers interviewed in the case studies claimed that so little guidance was provided from the design teams that it took an extremely long period for them to explore proper settings for heating in the BMS, and hence there was very high energy consumption in the first running year (Richard Wharton; Paul Andrew, interview, 2012). Consequently, one or more members of the design team (e.g. normally architects) are suggested to be present on site for "*typically four to six weeks immediately after move-in*" in order to provide timely help (BSRIA, 2014).

Once the initial aftercare period is over, the extended aftercare period is to review building performance and help users to get the best results of their building. After one-year occupancy, POE is suggested to be carried out to evaluate building performance in terms of environmental performance, energy efficiency, as well as occupant feedback. Designers should be able to discover problems from POE and provide fine-tuning to improve building performance, as what Architype did for School C. In Year 2 and 3, the reviews can be less frequent. The post-build service at this stage concentrates on monitoring and

recording the operation of the building, as well as reviewing building performance. The data recorded is very helpful for designers to use for future work, serving as research materials and design reference.

- Suggestions

The case studies suggest that architects should place great importance on aftercare service, as it not only affects building performance in practice but also reflects the responsibility of designers as well as their attitudes towards how to deliver 'good' architecture.

7.3 Summary – the model to improve building performance

Occupant comfort and satisfaction, quality of the indoor environment and operational energy efficiency are considered as three essentials to reflect building performance in this thesis. The first part of this chapter summarises the building performance of the five award-winning schools in the UK, compared with the relevant benchmarks and standards. It can be concluded that not all the selected cases branded with 'design excellence' achieved equivalently good building performance in practice, demonstrating discrepancies between the expected building performance and the actual building performance, and hence performance gaps. Unsuitability of the strategies employed and improper execution of the strategies proposed were considered as the chief reasons for the gaps between design intent and actual performance.

The cross case analysis shown at the second part of this chapter provides a valuable insight into the factors that could impact on building performance. It

suggests that the crucial elements for ensuring good building performance in use are related to the design process and aftercare service, while underlying the important role of architects from the inception of the design process to the period after handover. Nevertheless, given the small size of the sample (5 disparate case studies), generalisations on design process and aftercare service can hardly be made. The model of the process that interprets the key factors impacting on building performance is therefore developed from the early model shown as in Figure 7.2-1, illustrated as below.

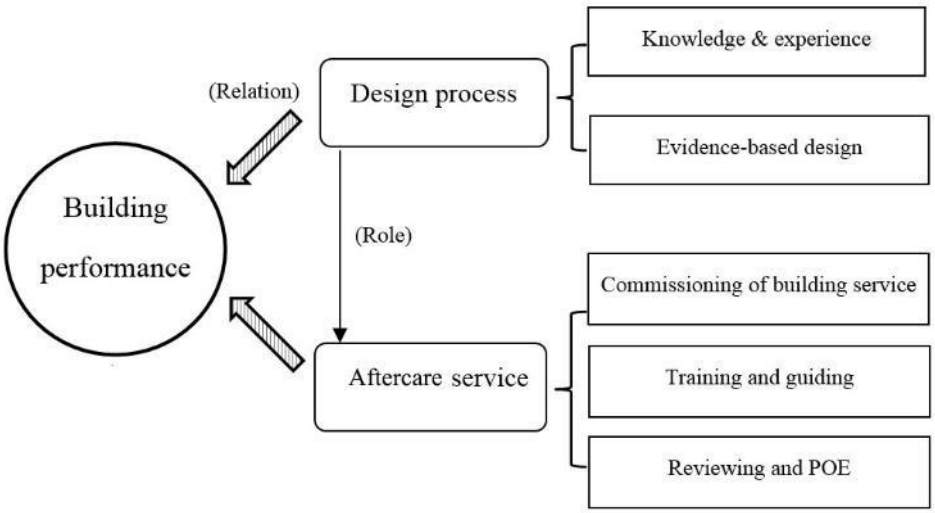


Figure 7.3-1: Developed model of the process - key factors impacting on building performance (source: Author).

Throughout the design process, design knowledge of architects acquired from experience, education and research plays an essential role in guiding the decision-making process, particularly in the intuitive stages of the process. Rich experience of sustainably environmental design can help designers make correct design decisions, hence contributing to ensuring building performance. Architects are, therefore, required to create and increase opportunities to obtain both tacit knowledge and explicit knowledge related to environmental design issues. Learning from the prior work, including both ‘internal’ work (i.e. the

projects designed by the architects) and ‘external work’ (i.e. related research or projects delivered by other practices), has a positive influence on the early decision-making process. Meanwhile, it could enhance design knowledge of architects and to gain valuable information as design reference for future work.

Another important factor related to the design process is the design approaches at different stages of the process. Evidence-based design (EBD), which provides evidence and information gained from many sources to help designers make design decisions, is a common but essential approach in architectural design, particularly sustainably environmental design in architecture. At the inception of the design process, pre-design analysis, such as site analysis, micro-climatic analysis, precedent study and consultation with clients and end users, provides useful information for designers to appreciate the situation, guiding the early decision-making process. At the feasibility stages of the design process, performance prediction analysis assisting with analytical tools can help designers check the feasibility of design decisions made at the intuitive stages, hence benefiting design outcomes. To maximise the function of EBD at the feasibility stages, it requires the use of convincing tools, updated approaches, as well as accurate refinement and modification to the early design decisions based on the results of performance predication analysis. In addition, architects are suggested to be involved in the EBD process as frequently as possible, in order to better understand how buildings should and will work in practice.

Besides the design process, aftercare service also has an essential impact on building performance. The common phenomenon that designers normally leave a project as soon as it is physically complete and handed over can easily cause performance gaps as well as unsatisfactory building performance in practice.

Members of the design team, particularly architects, are responsible of delivering buildings with right condition at the pre-handover stage. Further service, including guiding building users and facilities managers to operate buildings properly at the initial aftercare stage, reviewing and conducting POE at the extended aftercare stage, works effectively to ensure building performance in reality. In addition, the post-build service in terms of POE, reviewing and getting feedback from users benefits designers via learning from experience.

With good building performance is an essential manifestation of design excellence in architecture, it is sensible to infer that all the factors discussed above which have a great impact on building performance contribute to design excellence in architecture to a large extent. Hence, the model of the factors impacting on ‘building performance’ is then further developed into the model of factors influencing ‘design excellence’ in architecture, illustrated in Figure 7.3-2. The model interprets the idea that it is vital that all the factors discussed, i.e. knowledge and experience of designers, design approaches and post-build service, should be well managed by the design team, particularly architects, in order to achieve design excellence in architecture. Meanwhile, the role and responsibility of architects is, therefore, highlighted. The inferences from the case studies of this thesis have valuable implications for academic research, practice and architectural education, which are discussed in the next and final chapter.

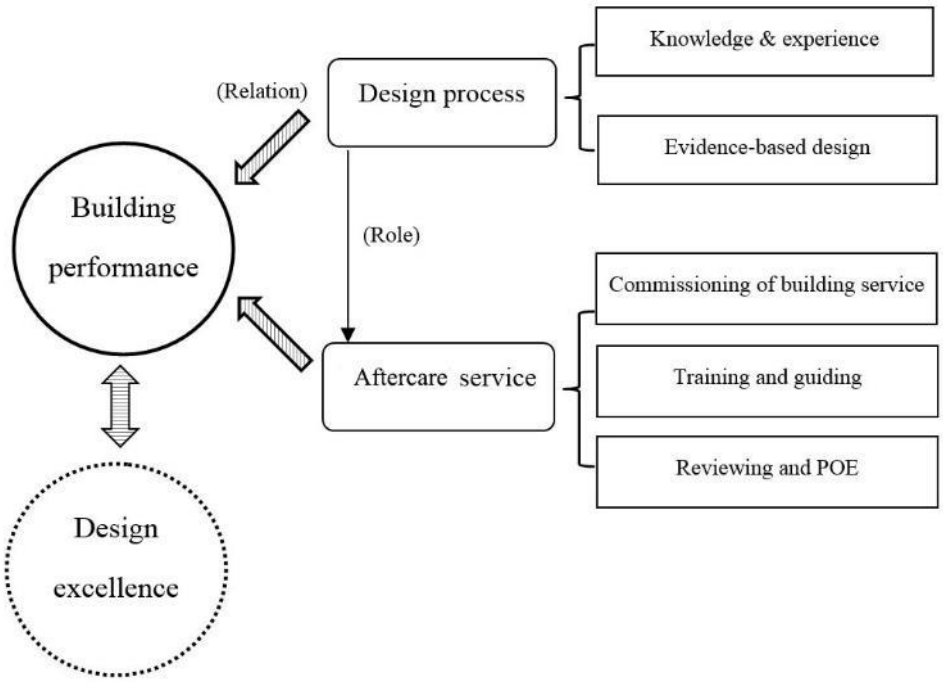


Figure 7.3-2: The model of factors impacting on 'design excellence' in architecture (source: Author).

Chapter 8 Conclusion

This chapter presents the main findings and implications of the work undertaken, summarising how the overarching aim and specific objectives were addressed and ultimately achieved. The contributions of the work to existing knowledge and practice are discussed, along with the implications on the RIBA Awards and the architectural profession.

8.1 Key findings of the research

The principal aim of this research project was to investigate whether buildings with design quality perform well in use, to understand the key factors affecting building performance and to explore how these factors should be managed by architects in order to generate more well-designed buildings, hence design excellence in architecture. This aim was achieved by undertaking the POE studies of five RIBA Award-winning schools to a certain degree, while addressing four specific research objectives. However, generalisations can hardly be drawn as the sample size is small and disparate, as well as the context of design, management and use matters. Key findings related to each of the objectives are summarised below.

- Objective 1: Develop an approach for conducting POE studies of high performing schools (or buildings) in order to have had a lot of care and support in its production.

A literature review, particularly referring to POE studies of schools and the

methods of POE, was conducted to explore a suitable methodology for POE studies of RIBA Award-winning schools. The diagnostic level of POE studies using the case study approach was selected as the principal methodology of this research. BUS Occupant questionnaires with the school staff and interviews with the headteachers and site managers were conducted to explore occupant perceptions regarding the selected schools in use. Both design-related and performance-related variables were assessed in the questionnaire.

For the assessment of environmental performance, CBDM via DAYSIM calculating UDI indexes in the specified classrooms was carried out. Daylighting performance in terms daylight sufficiency and distribution inside of the space was assessed via this approach, covering different sky conditions based on the real weather data, hence ensuring dependable assessment results. Compared to the empirical measurement, i.e. DF approach, it provides a comparatively comprehensive analysis rather than only daylighting performance under overcast sky conditions. For the assessment of ventilation performance, a quick assessment via an Excel spreadsheet, i.e. Optivent, was undertaken in order to have a basic understanding regarding whether cooling loads in summer can be achieved by cross ventilation in the schools studied. The lack of measuring internal level of CO_2 concentration was a limitation of this research for assessing ventilation performance. With regard to thermal environment achieved in the schools, on-site measurement of interior dry bulb temperature and relative humidity was undertaken for several learning and working spaces specified, for both summer and heating months.

For the evaluation of energy performance, the lack of meter readings and BMS data is an obvious limitation of the assessment approach employed. Nevertheless, EPCs and DECs collected provided the data of annual energy

consumptions as well as annual carbon emissions of the schools studied, in comparison with the relevant benchmarks. The approaches of the POE studies of schools can be further improved by choosing more sensible assessment methods for ventilation performance and energy performance. Nevertheless, a guidance consisting of the following KPIs: occupant satisfaction and comfort, indoor environment quality and energy performance, was summarised for POE studies of non-domestic buildings.

- Objective 2: Assess actual building performance of the RIBA Award-winning schools selected via the approach developed according to Objective 1, in order to find out if there is the 'Performance Gap' between the design aspirations of the designers and building performance in use.

POE and BPE studies were conducted to assess building performance of the selected RIBA Award-winning schools in practice, in terms of the three KPIs defined. The evaluation results were compared with the relevant benchmarks.

The POE results revealed that occupant satisfaction about the overall design quality, particularly architectural expression, was achieved in all the five schools studied generally. However, a series of environmental issues, such as inadequate daylight, ventilation inefficiency and thermal discomfort, and issues related usability, such as operation difficulty and the lack of training, were found as common problems which occurred in three of the five schools studied (i.e. School B, D and E), indicating that the level of occupant comfort was not fully achieved in these schools. On the other hand, the BPE analyses demonstrated that not all the 'well-designed' schools performed as well as

anticipated, and the analysis results generally corresponded with the occupant feedback regarding the schools' indoor environment. Hence, discrepancies between the design intent and the design outcomes (i.e. building performance) were demonstrated. Unsuitability of the environmental strategies proposed at the intuitive stages and improper performance prediction analyses at the feasibility stages were considered as the contributing factor to performance gaps.

- Objective 3: Investigate the essential (design) factors impacting on building performance and how these factors can be managed to improve building performance.

Learning from the case studies, design process and aftercare service were deemed as the factors that possibly have a great impact on building performance. It can be seen that building performance of the schools studied was better where design team was more informed, kept a close watch on the design process and undertook aftercare service. However, the sample size of this research (i.e. five RIBA Award-winning schools) is small and disparate. Generalisations can hardly be drawn as the context of design, management and use matters. In addition, the impact of construction stage and workmanship issues on building performance was not discussed in the case studies, deemed as limitations of this research.

For the design process, it can be observed that building performance could be influenced by the design-related factors such as knowledge and experience of architects and design approaches adopted at different stages. Through a series of comparative analyses, knowledge of architects in sustainably environmental

design, which can be acquired from both design experience and research, was conceived as an essential element to benefit the early decision-making process. On the other hand, effective evidence-based design at different phases of the design process was found as a necessity to ensure design outcomes (i.e. building performance in practice) consistent with design intention. The case studies indicate that pre-design analyses, including site analysis, micro-climatic analysis, precedent studies and consultations with clients and end users, can provide useful information to guide the early decision-making process, while precedent studies can be exceptionally helpful to either an under-going project or future works.

For the feasibility stages, the performance prediction analyses via updated approaches and suitably analytical tools was deemed as a 'must-have' approach to assure the effectiveness of design decisions, especially environmental design decisions. Architects were suggested to contribute to this analytical process as much as possible, requiring rich knowledge of environmental design issues and the relevant analytic skills. In addition, for the achievement of good building performance, the need of accurate design modification and refinement based on the results of performance prediction analyses was emphasised through cross the case studies.

Further evidence of the impact of aftercare service on building performance was highlighted through an investigation of the relationship between the aftercare service conducted and actual energy performance of the schools studied. Aftercare service at different stages of the aftercare period was suggested to be undertaken by the design team (particularly architects), including commissioning of building service at the pre-handover stage, training occupants and facilities mangers and on-site observation at the initial aftercare

stage, as well as POEs and reviewing at the extended aftercare stage.

- Objective 4: Rethink of the judging of ‘design excellence’ in architectural design awards and provide suggestions regarding the assessment of ‘building performance’ in architectural awards.

This objective is the last but the most fundamental and comprehensive objective of this thesis. Meanwhile, the findings of this objective can be considered as one of the contributions of this research project which can refer to Section 8.2.3.

8.2 Contribution to knowledge and practice

The findings of this PhD project provide three contributions to existing theory and practice. These fall under the following definitions of original contribution: ‘bringing new evidence to bear on an old issue’; ‘taking a particular technique and applying it to a new area’ and ‘adding to knowledge in a way that has not been done before’ (Phillips, 1993).

8.2.1 Contribution 1 – An evaluation guidance

The first contribution is the establishment of guidance composed of three KPIs including seven performance indexes for the evaluation of building performance.

Three parameters – occupant feedback in terms of comfort and satisfaction levels, environmental performance and energy efficiency – derived from the review of the performance-related criteria of the RIBA Awards and relevant

literature were deemed as the KPIs for evaluating building performance. According to the findings of the case studies, building performance of the selected cases summarised from the empirical research evidence demonstrated the *validity* and *rationality* of the three KPIs defined to assessing building performance. Consequently, guidance consisting of the three KPIs was summarised in Figure 7.1-1 for the evaluation of building performance, and it is applicable for assessing performance of different types of buildings, particularly non-domestic buildings.

Based on the guidance, the evaluation of building performance was conducted from the *synthesis* of the three key performance aspects rather than simply relying on any individual parameter. It provided a relatively comprehensive understanding towards realistic building performance from both qualitative and quantitative aspects. An evaluation system that comprises seven performance indexes related to the three KPIs was further constructed, which provides fundamental guidance for POEs, allowing the evaluation process undertaken in a holistic manner (see Figure 8.2-1). Detailed performance indexes involved in the evaluation guidance are shown on Figure 8.2-1.

For the seven indexes, the corresponding assessment methods are various. It is noteworthy that, in terms of the evaluation method of daylighting performance, the author combined the real configuration of the selected schools and their surroundings into the climate-based daylight analysis, which has been normally used in performance prediction analysis during the design stages. With the analyses results mostly consistent with the occupant perception regarding daylight quality of the schools, this approach was deemed as a sensible and realistic approach for the evaluation of daylighting performance used in POE studies.

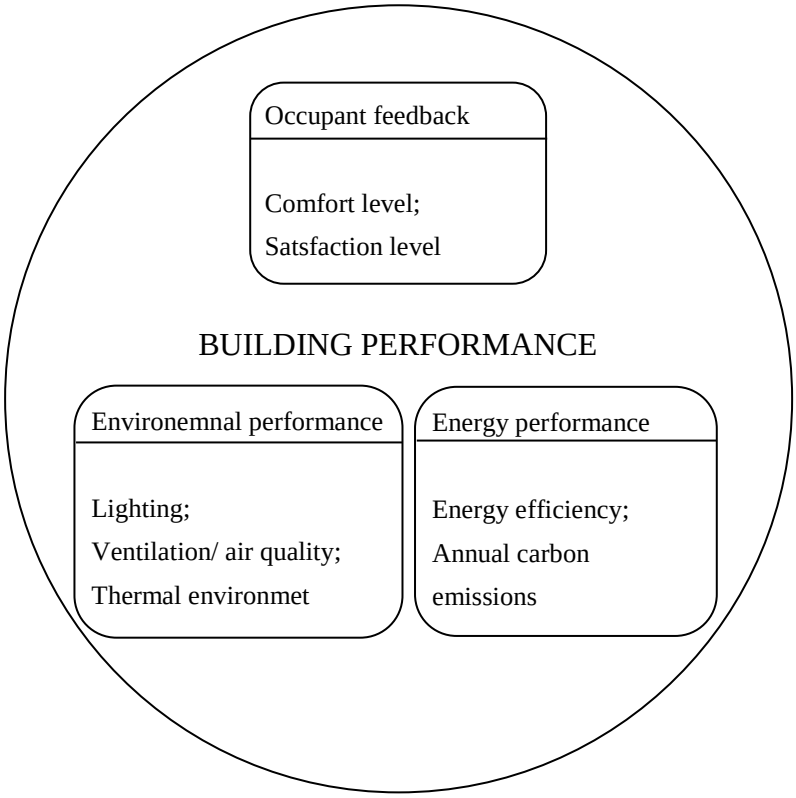


Figure 8.2-1: The synthetic evaluation system of building performance (source: Author).

8.2.2 Contribution 2 – Challenges and constraints of conducting POE studies

The second contribution is to summarise challenges and constraints of conducting POE studies drawn from the experience of the POE studies conducted in this research. The corresponding recommendations can be used as a reference for future POE studies of non-domestic buildings, especially schools.

As POE plays an important role in exposing problems in practice and identifying advantages and disadvantages of design strategies and technologies, it can assist designers and occupants with solutions to improve building performance (Craig M. Zimring, 1980; Turpin- Brooks, 2013). To conduct a

rigorous POE study, Turpin-Brooks (2013) suggests that the relevant assessment, such as an objective measure of client satisfaction and the assessment of the impact of sustainable strategies and technologies on building occupants' experience, can be realised in most depth by adopting a case study approach. Nevertheless, the difficulties found in this research project by the author highlight several challenges and constraints when conducting POE studies using the case study approach in schools. The corresponding experience and findings can benefit other researchers for future POE studies.

For the POE studies of schools, *the first challenge is to obtain ethical approval and to get access and permissions to conducting surveys or questionnaires with school users*. Before getting access to schools, it is suggested to consider rationally whether all school users are necessary to be involved in the POE study. According to Leaman and Bordass (2001), pupils in primary schools whose ages are under eleven are suggested not being involved in surveys, as their answers were considered less reliable in comparison with adults' feedback. In addition, the review process is very restricted to grant ethical approval for the study involving children due to the relevant legal protection. It may take a relatively long period for the application to be reviewed and granted in comparison with the one without children involved, hence influencing the progress of the POE. Nevertheless, for the POE studies in secondary schools or academies, students who could understand questions properly and deliver relatively convincing answers to questionnaires can be involved in POE studies, in order to provide different views as the school staff.

To apply for ethical approvals regarding a research study involving human participants, detailed application documentation is required to be submitted. The documentation should normally include research proposal, ethical issue

checklist, information consent letters for interview studies and questionnaires, corresponding consent forms, specific questions of interviews, as well as the templates of questionnaires. The author attached the corresponding documentation of this research in Appendix 1, which can be used as a reference for other researchers.

When it comes to getting access and permissions to schools, it is essential to connect with the 'right' person at the inception of a POE study. The author suggest to contact with the headtecher or the deputy of a school as the first choice. With their permissions and support, school users involved in the POE, i.e. students or school staff, could pay more attention to the study, consequently benefiting the efficiency of data collection and the data's dependability.

The second challenge is related to the design of a POE – *to identify the aims of a POE based on the research objectives and to choose the right level of a POE, i.e. suitable methods*. At the designing stage of a POE, the author found that researchers may prefer to completely rely on well-established tools, such as BUS occupant questionnaires, for data collection, but sometimes ignore the purposes of the POE undertaken. This type of tools has been designed by professionals, acknowledged by the profession and used worldwide, hence reliability and feasibility in terms of data collection. However, it may provide overloaded data irrelevant to the study.

For the POE studies undertaken in this research project, the author used BUS Occupant questionnaires supplemented with interviews to investigate school users' perceptions regarding the schools' performance in use. The use of the questionnaires provided very useful data to achieve research objectives, while some variables, such as "ages" and "travel", are not necessary for the

investigation. The various variables contained in the questionnaire may have a negative impact on the participants' patience, and can increase the amount of data to be analysed. Consequently, the author suggest that researchers can mark unwanted variables clearly on the questionnaire before distributing questionnaires to the participants. Additionally, to understand the aims of a POE clearly at the early research stage can help researchers set up a clear direction of data collection, avoiding useless data and increasing reliable data, hence benefiting reasonable design of a POE.

According to Preiser (2001) and Langston and Ding (2001), there are three levels of effort in the POE process – the indicative, the investigative and the diagnostic level (Turpin- Brooks, 2013). For the three levels, aims, corresponding methods and timescales of the POE are various. Based on the POE studies in this research project, the author suggest that it is necessary to adopt the diagnostic level using the methods of sophisticated data gathering, physical measurement and analysis techniques when evaluating building performance in use, besides questionnaires and interviews. It is important to understand that respondents may not all react and perceive their environment in the same manner (Turpin- Brooks, 2013). Regarding the specific methods used in the POE studies, detailed suggestions are listed as below in accordance with the challenges and constraints of the POE studies undertaken in this research project.

- When evaluating a building's daylighting performance in terms of daylight sufficiency, distribution and the possibility of glare or visual discomfort, building visits and on-site illuminance measurement (i.e. Daylight factor approach) can provide a quick understanding regarding the daylighting environment but less accurate assessment results. In

order to evaluate the daylighting environment in use precisely, the method of climate-based daylight modelling using the annual weather data, i.e. via DAYSIM, is recommended by the author. Although the original purpose of CBDM is to assist designers to predict daylighting performance as accurately as possible during the design stage (Mardaljevic, 2006), the author found that daylighting performance of the schools evaluated via this approach in the case studies mostly corresponds to the occupant feedback via BUS Occupant questionnaires, hence feasibility in POE studies.

To use the CBDM for assessing daylighting performance in use, it is noteworthy that all the parameters relevant to the simulation should be as accurate as possible in order to deliver precise results. These parameters include orientation of buildings, dimensions of the spaces examined, configurations of daylight sources and properties of interior materials. These information can be obtained from designers.

- When evaluating ventilation performance and thermal environment of a building in use, empirical measurements provides more realistic data in comparison with the results of computerised simulation. For schools, the interior level of CO_2 concentration is an essential factor of air quality, hence reflecting ventilation performance. To measure the indoor CO_2 level of a learning space, data sensors are required to be installed inside of the space monitored to measure real data for a certain period. Alternatively, relevant data can be withdrawn from the computer linking with the BMS. In the case studies of this research project, ventilation performance of the schools studied was assessed simply via

a calculation tool – an excel spreadsheet, i.e. Optivent. This tool can provide a quick calculation to assess whether or not cooling loads can be achieved in the selected space via cross ventilation. However, it can hardly evaluate the real performance when occupants actually use the space. This is a constraint of the POE studies undertaken in this research project.

For the evaluation of a school's thermal environment in use, empirical measurement is also suggested as a suitable method. Data loggers, which can record timely parameters such as dry bulb temperature and relative humidity, are recommended for on-site measurements. Based on the author's experience of undertaking empirical measurements in the schools studied, the researcher should inform the school the following information before conducting any measurements: *purposes of the measurements, relevant equipment to be installed in the school and the period of on-site measurements*. In addition, it is essential to notify the school staff who manage the spaces monitored to look after the equipment installed in order to ensure the 'safety' of the equipment, hence minimising the opportunity of data losses. The author suggest to take on-site measurements both in summer months and heating months. Each period is no less than three weeks to ensure data's reliability.

- When using the approach of BUS Occupant questionnaires with school users, the author highlighted the importance of possible 'revision' of the questionnaire. In addition, it is suggested to ask the help from the headteacher or others to distribute and collect the questionnaires. Although Leaman (2005) suggest that it is better to distribute and

collect questionnaires by the researcher, it is difficult to achieve this in schools as rare participants of schools can finish questionnaires and get back to the researcher within a relatively short period. They are busy with teaching or other activities, more or less.

8.2.3 Contribution 3 – Judging 'building performance' in the RIBA Awards

The third contribution is the analysis of design process and aftercare service, as well as their impact on building performance, implying that the awards submission should stress on documentation related to these elements when judging building performance in architectural design awards.

When it comes to the judging of performance-related factors in a majority of architectural awards today, the judgement is normally dependent on the jury's professional knowledge, on-site audits and predicted performance data provided by the awards entrants, due to the 'time' effect of the awards. However, according to the Soft Landings Framework, the performance gap between the favourable building performance and the actual building performance can exist at any stage, i.e. from the inception and briefing to the period after handover (Bordass et al., 2004; Menezes et al., 2012). This may ultimately affect the precision of the judgement regarding 'design excellence' in architecture.

This research suggests that the design process and aftercare service were the design-related factors possibly contributing to building performance in use. In order to make the judging of architectural design awards more sensible, the author put forward that the consideration of *the design process* and *aftercare service* of a project should be involved in the judging process of architectural

design awards, i.e. RIBA Awards within the context of this research, besides the current criteria. It intends to help the jury to make sensible decisions regarding performance-related factors in the judging process, compensating for the criteria of design excellence in architecture.

When estimating whether 'the design process' of a project is successful to deliver buildings with good performance, the consideration of design knowledge, experience and sustainable attitudes of architects (or architectural practices) towards sustainably environmental design, as well as design approaches adopted at different stages of the design process was required to be involved in the judging process. When valuing aftercare service of a project in architectural awards, the judges were suggested to consider what aftercare service has been adopted or planned to be conducted to the project by the design team in accordance with the research findings. Accordingly, it suggests that the awards submission should stress on documentation related to these elements for all awards entries. However, with the small research sample, generalisations can hardly be made, hence research limitations.

8.3 Implications

With the increasing demand of 'environmentally responsible' buildings, this research project reconsiders the connotation of 'design excellence' in architecture via the aspect of 'building performance'. The investigation of building performance of the award-winning schools selected highlights the limitations of the architectural awards today when it comes to the judging of performance-related factors. Insights into the factors that impact on building performance through the case studies are beneficial to improve and perfect the judgement of 'building performance' in architectural awards, and hence

enhancing the criteria of design excellence in architecture. This research project emphasises the importance of building performance when valuing a building's design quality, and suggests that BPE should be made mandatory for all entries for RIBA awards and other architectural excellence awards.

A noteworthy issue was re-investigated in this research project that the performance of 'well-designed' buildings acknowledged by the public may be not good enough to provide occupant comfort and satisfaction or high energy efficiency. This issue underlines the significance of undertaking BPE studies for all entries for RIBA Awards, and possibly other architectural design awards. It intends to minimise the spread of misleading messages regarding 'what good architecture is'.

On the other hand, it is reasonable to suggest the RIBA to establish another 'design excellence' awards programme, aiming to reward the original award-winning projects which achieved good building performance in use after a few year of occupation based on a valid POE study. The POE studies should be done by a third party. This action could contribute to delivering 'truly' good architecture via discovering and improving actual building performance of the original award winners. Meanwhile, it contributes to building up a database or a platform of good architecture, allowing designers to learn design correctness and design faults from prior work and to explore useful design reference.

The research findings also emphasise the role and responsibility of architects in delivering well-designed buildings with good building performance that architects are required to be highly involved from the inception of the design process to the aftercare period. Architects' design knowledge, experience, and particularly understanding towards environmental design issues in architectural

design, are considered as the essentials to ensure design excellence in architecture. Hence, the issue of how to train ‘environmentally responsible’ architects deserves great attention of the architectural profession. Architects should also push themselves to be masters of controlling both the design process in terms of making correct design decisions and the aftercare period in terms of providing proper and prompt suggestions and improvements.

8.4 Limitations of the research and future work

8.4.1 Limitations of the research

At the onset of this PhD project, the research covered a relatively wide scope, aiming at exploring the connation of ‘design excellence’ in architecture. As the definition of ‘good architecture’ is elusive, it took a relatively long period to search a proper direction to conduct the research. Taking the architectural awards (i.e. the RIBA Awards) as a breakthrough point has helped to address this issue, whereas it is obvious that this research project was carried out under a hypothesis that receiving awards, particularly awards with high reputation, represents the achievement of ‘design excellence’, which may need further consideration.

The second limitation of this research was related to the small sample size, leading to relatively limited conclusion. As this research is a self-funded project, all the field studies, including BUS Occupant questionnaires, interviews and on-site data collection, were conducted by the author solo. This resulted in numerous barriers and challenges. The first one was to gain support from the architectural practices which won the RIBA Awards. Although most of the architectural practices who the author contacted with at the beginning of

this research showed certain willingness to be involved in the research, only few of them provided supportive evidence, such as detailed drawings of the projects, and accepted to be interviewed. The second barrier was to obtain access and permission to the schools to undertake the field studies. This resulted in a limited number of the cases involved in this thesis and a significant proportion of the research time being taken on the negotiations with the selected schools. Additionally, lack of coherence in the selection of schools (i.e. primary, secondary schools and academies) is also a limitation, as different types of schools meet different complexity.

The third limitation is related to the simulation reliability of ventilation performance. To evaluate ventilation performance of the selected schools, a relatively simple calculation regarding the achieved air flow rates was undertaken via the Optivent program. As mentioned previously, this program can only provide the prediction of ventilation efficiency for the scenario of 'stack' effect, resulting in incomprehensive analyses when the schools are single-sided ventilated or mechanically ventilated. In addition, other parameters related to air quality in schools, such as the indoor CO_2 concentration, were not considered in the performance analysis due to the lack of relevant equipment. For the thermal analyses, the length of the on-site monitoring periods was relatively short and the monitoring time was slightly various to different schools, due to the limited number of the equipment (i.e. Ting-tags) and the availability of the schools for on-site monitoring. This resulted in that the data collected may only represent the thermal environment under certain conditions, i.e. extreme conditions.

The forth limitation is the lack of proper energy analysis – over time and by end uses. CIBSE TM22 could have been undertaken. In addition, no BMS data

was included in the research, leading to uncompleted analyses of energy performance in use.

Despite these limitations, this research project has successfully achieved its overarching aim by providing the insight into the key parameters impacting on building performance, and analysing how these factors should be managed by architects in order to deliver buildings with good performance, hence quality architecture. Four specific objectives were fulfilled, generating significant outcomes that contributed to the achievement of the aim of this thesis. The research has culminated in a guidance for evaluating building performance in use. The guidance, as a synthetic system composed of seven performance indexes, is capable of being used to assess performance of different types of buildings. Furthermore, the research has contributed to the knowledge of conducting POE studies of schools, and has enhanced the judging and criteria of architectural design awards providing sensible methods for the jury to judge performance-related factors. Cumulatively, the outcomes of this project have great scope to ask the architectural profession to reconsider the definition of design excellence in architecture, with the purpose of helping architects to deliver more well-designed buildings.

8.4.2 Future work

The future work can be divided into two parts. The first part is to carry out a proper evaluation of energy performance and ventilation performance of the selected award-winning projects. Meter readings and energy breakdown need to be carefully assessed, as well as the use of BMS data, in order to understand the reason for high electricity consumption of the schools studied. The on-site measurement of indoor CO_2 concentration of the selected classrooms should be

conducted, in order to investigate the actual ventilation performance of these award-winning schools.

The second part is to conduct more POE studies of RIBA Award-winning schools, including both occupant feedback and BPE studies. It intends to generate more meaningful conclusion regarding actual building performance of award-winning projects based on sensible sample size. In addition, a journal paper in accordance with the main findings of this thesis is under preparation.

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Appendices

Appendix 1: Ethical approval application template for the research involving human participants

Ethical Issues Checklist

The purpose of this Checklist is to facilitate the review process and to identify any ethical issues that may concern the Committee. It is meant to be an aid to both the researcher and the Committee. Listed below are areas which require some justification and attention on your part in specifying your study protocol. Please answer each question honestly, giving full details where required. Answering "YES" to any of the questions will not necessarily lead to a negative response to your application but it will draw issues to your attention and give the reviewers the opportunity to ensure appropriate steps are being taken. In expedited review, supervisors should ensure that for any questions where the answer "YES" has been given, appropriate measures have been taken to maintain ethical compliance.

Applicant's full name: YANTI CHEN

You must complete ALL of this section before submitting your application

1 Who is the population to be studied?

Group A: RIBA panel members, some professionals involving architects, theorists and professors at Schools
Group B: Staff of the selected primary school and secondary school.

2 Please give details of how the participants will be identified, approached and recruited. (Include any relationship between the investigator and participants e.g. instructor-student).

People in Group A are treated as the interviewees for a pilot interviewing study. (interviewer-interviewee)
People in Group B are the staff in selected school buildings, and they will be recruited by questionnaires. (interviewer-survey participants)

3 Will the population studied include any vulnerable members of the public? **YES** ☐ **NO** ■
Note: for the purpose of ethics approval this includes participants who are under 18, people who are disabled or in poor health, and also those who are non-English speakers and may not be able to understand the consent forms. (If YES, please give further details)

4 Will it be possible to associate specific information in your records with specific participants on the basis of name, position or other identifying information contained in your records? **YES** ■ **NO** ☐

5 What steps have you taken to ensure confidentiality of personal information and anonymity of data both during the study and in the release of its findings?

For the interviewees who attend the face-to-face interviews, they will be asked for permissions if the answers are able to be published in my future research. The interviews are recorded with the permission of every interviewee, and they can keep the interview transcriptions if they wish.

For the participants of the survey, their private information (such as name, position, etc.) would only be reviewed by the investigator (Yanti Chen), and the data of their answers would be analysed by me and Adrian Leaman who is professional in doing post occupancy evaluation. The survey is under the safety documentation of keeping confidentiality of personal information.

Any private information of the participants is not the main part of the research, therefore, it is not necessary to provide their personal information if the participants are not willing to.

6 Describe what data will be stored, where, for what period of time, the measures that will be put in place to ensure security of the data, who will have access to the data, and the method and timing of disposal of the data.

Basically, the data can be divided into two categories. One is the interview voice records that would be stored by me in my own computers and the transcripts of those interviews would be sorted out after transcription, and then some of the answers would be presented in the research project with the permission

of interviewees. Another is the survey which will be finished by students and the staff of selected cases. The questionnaires would be printed out and distributed to participants, and those data would be only analysed by me and Adrian Leaman who designed the post-occupancy evaluation survey.

All the data would be treated during my PhD process (2012-2013). Interviews will be transcribed and then sorted out by myself. The data from the questionnaires designed by Adrian Leaman would be sent to his company for analysing, and the result would be reanalysed by me and be saved in his building database system which is confidential. Analysing diagrams will be presented as the data analysing results. The participants who will participate the survey process would be the staff in selected schools. Another type of questionnaire designed by me will be analysed by me, and the targets are the students in selected schools.

All the data from the questionnaires are related to buildings' physical performance, represented by occupant feeling. Nothing regarding participant's personal information would be used in the data analysis.

.....

7	Will persons participating in the study be subjected to physical or psychological discomfort, pain or aversive stimuli which is more than expected from everyday life? (If YES, please give further details)	**YES** ☐	**NO** ■
	.....		
8	Will participants engage in strenuous or unaccustomed physical activity? (If YES, please give further details)	**YES** ☐	**NO** ■
	.....		
9	Will the investigation use procedures designed to induce participants to act contrary to their wishes? (If YES, please give further details)	**YES** ☐	**NO** ■
	.....		
10	Will the investigation use procedures designed to induce embarrassment, humiliation, lowered self esteem, guilt, conflict, anger, discouragement or other emotional reactions? (If YES, please give further details)	**YES** ☐	**NO** ■
	.....		
11	Will participants be induced to disclose information of an intimate or otherwise sensitive nature? (If YES, please give further details)	**YES** ☐	**NO** ■
	.....		
12	Will participants be deceived or actively misled in any manner? (If YES, please give further details)	**YES** ☐	**NO** ■
	.....		
13	Will information be withheld from participants that they might reasonably expect to receive? (If YES, please give further details)	**YES** ☐	**NO** ■
	.....		
14	Will the research involve potentially sensitive topics? (If YES, please give further details)	**YES** ☐	**NO** ■
	.....		

If you require space for additional information, please add it here and identify the question to which it refers:

INFORMATION CONSENT LETTER FOR INTERVIEW STUDY

Letter:
Dear Sir or Madam,

My name is Yanti Chen, studying at the Department of Architecture and Built Environment, University of Nottingham, where I am doing my PhD degree supervised by Professor Brian Ford.

For my research, I am interested in how to balance the design quality and environmental design in architecture, and currently exploring the relationship between 'design excellence' and building performance in terms of energy performance and occupant perception regarding the buildings in use. Some award winning buildings (a measure of design 'excellence') have been selected as research examples with particular reference to educational buildings. In order to better understand the relationship between 'design excellence' and building performance in school design, I am seeking the views of professionals in different fields. Therefore, I would be very grateful if you could kindly accept a face-to-face interview (less than an hour) with me towards this topic. The interview will mainly focus on this topic, without restrictions of the content. I know that you are very busy, so please suggest a date based upon your schedule.

You may decline to answer any of the interview questions if you so wish. Further, you may decide to withdraw from this study at any time without any negative consequences by advising the researcher. With your permission, the interview will be audio recorded to facilitate collection of information, and later transcribed for analysis. All information you provide is considered completely confidential. Your name will not appear in any thesis or report resulting from this study, however, with your permission anonymous quotations may be used. Data collected during this study will be retained for (2012-2013) in a locked office in my Department. Only researchers associated with this project will have access. There are no known or anticipated risks to you as a participant in this study.

If you have any questions regarding this study, or would like additional information to assist you in reaching a decision about participation, please contact me at (07552148148) or by email at (laxyc12@nottingham.ac.uk; yantichen1110@gmail.com). You can also contact my supervisor, Professor (Brian Ford) by email (brian.ford@nottingham.ac.uk).

I sincerely hope this would not bother you too much, and you could accept this request. I look forward to hearing from you soon. If you have any question please no hesitate to let me know.

Best regards,

Your sincerely,

Yanti Chen

PhD candidate
The Department of Architecture and Built Environment
University of Nottingham

Address:
2 Broughton Street,
Beeston,
Nottingham
NG9 1BD
Mobile: 07552148148
Email: laxyc12@nottingham.ac.uk; yantichen1110@gmail.com

INFORMATION CONSENT LETTER FOR QUESTIONNAIRES

Letter to Staff:
Department Architecture and Built Envrionment
Faculty of Engineering
University of Nottingham

Dear Participants,

My name is Yanti Chen, studying at the Department of Architecture and Built Environment, University of Nottingham, where I am doing my PhD degree supervised by Professor Brian Ford.

The project I am doing is to explore the relationship between 'design excellence' and building performance in terms of energy performance and occupant perception regarding the buildings in use. Your school, (xxx) as a RIBA Awards winning building, has been selected as a case study in this research.

Attached to this letter is a 3-page questionnaire developed by BUS Methodology for dieticians to assess your feelings on issues relating to actual building performance. Through your participation in the questionnaire, I hope to ascertain the varied towards different aspects related to building performance, such as building image, lighting condition, thermal comfort, system control and perceived productivity, etc.

All information that you provide through your participation in this study will be kept confidential. Further, you will not be identified in the thesis or in any report or publication based on this research. There are no known or anticipated risks to participation in this study. The data collected through this study will be kept for a period of (2012-2013) in a secure location. Your participation in this study is completely voluntary so you can withdraw from the questionnaire at any stage.

The questionnaire should take about 10 – 15 minutes to complete, but there is no time constraint. There are also no right or wrong answers, so you actual feelings toward each question would be very helpful to my research. I understand that your time is at a premium but your opinions are very valuable to me, and are beneficial to improve the future building design.

It would be appreciated if you would return the completed questionnaire to the investigator or any staff who is responsible to distribute the questionnaire. After careful and precise analysis of the data obtained from this questionnaire, I will be happy to provide you with a copy of our findings at your request. Thank you in advance for your time and participation. If any questions do arise, feel free to contact us at your convenience

Yours sincerely,
Yanti Chen

PhD candidate
The Department of Architecture and Built Environment
University of Nottingham

Address:
2 Broughton Street,
Beeston,
Nottingham
NG9 1BD
Mobile: 07552148148
Email: laxyc12@nottingham.ac.uk; yantichen1110@gmail.com

Consent Form for Interview:

CONSENT FORM

By signing this consent form, you are not waiving your legal rights or releasing the investigator(s) or involved institution(s) from their legal and professional responsibilities.

I have read the information presented in the information letter about a study being conducted YANTI CHEN of the Department of Architecture and Built Environment at the University of Nottingham. I have had the opportunity to ask any questions related to this study, to receive satisfactory answers to my questions, and any additional details I wanted.

I am aware that I have the option of allowing my interview to be voice recorded to ensure an accurate recording of my responses.

I am also aware that excerpts from the interview may be included in the thesis and/or publications to come from this research, with the understanding that the quotations will be anonymous.

I was informed that I may withdraw my consent at any time without penalty by advising the researcher.

With full knowledge of all foregoing, I agree, of my own free will, to participate in this study.

☐ YES ☐ NO

I agree to have my interview audio recorded.

☐ YES ☐ NO

I agree to the use of anonymous quotations in any thesis or publication that comes of this research.

☐ YES ☐ NO

Participant Name: _____ (Please print)

Participant Signature: _____

Witness Name: _____ (Please print)

Witness Signature: _____

Date: _____

Appendix 2: Questionnaire to headteachers and BUS Occupant questionnaire

Survey to Clients

These are ten main issues with some detail questions (refer to CABE's 10 criteria) related to school design, please give your answers. It will take around 15 minutes to finish.

This survey is being conducted to help with future planning and design of school buildings. The information collected will be treated as completely confidential by the Yanti Chen, only for research purposes.

Thank you for your help and support!

Queries:
If you have any queries please contact Yanti Chen
Email: yantichen1110@googlemail.com; Tel: 07552148148
Address: 2 Broughton Street, Beeston, Nottingham NG9 1BD

Project name:

Clients:

1. **Identity and context**: making a school the students and community can be proud of
(How would you rate the degree of satisfaction of this project on this issue? Please "√")

Overall satisfaction of the completion Please tick

Unsatisfactory | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Satisfactory

- **School ethos and identity**
  a. Does the design help foster pride and ownership in the school?

Unhelpful | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Very Helpful

  b. Is the school design inviting to the local community?

Unsatisfactory | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Satisfactory

- **Civic character**
  a. How satisfied were you with the design strengthening the image of education locally?

Unsatisfactory | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Satisfactory

Any comments:

2. **Site plan**: making the best use of the site

Overall satisfaction of the completion Please tick

Unsatisfactory | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Satisfactory

- **Strategic site organisation**
  a. How satisfied were you with the buildings, grounds and facilities arranged on the site?

Unsatisfactory | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Satisfactory

Any comments:

---

3. **School grounds**: making assets of the outdoor spaces

Overall satisfaction of the completion Please tick

Unsatisfactory | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Satisfactory

- **Relationship between the grounds and building**
  a. How satisfied were you with the design respond to the existing topography, climate and ecology of the site?

Unsatisfactory | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Satisfactory

- **Social spaces and play**
  a. How satisfied were you with outdoor spaces provided for a variety of different student social activities, interest ranges and group sizes?

Unsatisfactory | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Satisfactory

- **Outdoor learning**
  a. How well do the learning spaces support the school's pedagogy and the curriculum?

Not at all | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Very well

- **Physical activity**
  a. Do the grounds facilitate community use?

Yes ☐ No ☐

Any comments:

4. **Organisation**: creating a clear diagram for the buildings

Overall satisfaction of the completion Please tick

Unsatisfactory | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Satisfactory

- **Accommodating the educational agenda**
  a. Is this successfully accommodated in the internal arrangement of spaces?

Yes ☐ No ☐

- **Spatial organisation**
  a. How satisfied were you with the learning spaces arranged across the school?

Unsatisfactory | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Satisfactory

- **Movement routes**
  a. How satisfied were you with the links between indoor and outdoor spaces?

Unsatisfactory | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Satisfactory

Any comments:

---

5. **Buildings**: making form, massing and appearance work together

Overall satisfaction of the completion Please tick

Unsatisfactory | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Satisfactory

- **Concept**
  a. Is there a coherent design idea that relates plans, sections and elevations?

Yes ☐ No ☐

- **Form and massing**
  a. How satisfied were you with the building's form and massing to the site?

Unsatisfactory | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Satisfactory

  b. How satisfied were you with the height of the building considered from educational and massing perspectives?

Unsatisfactory | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Satisfactory

design, colour, pattern and texture, etc?

Unsatisfactory | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Satisfactory

- **Construction and materials**
  a. How would you rate the materials and fabrics used?

Hard to maintain | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Durable

Any comments:

---

6. **Interiors**: creating excellent spaces for learning and teaching

Overall satisfaction of the completion Please tick

Unsatisfactory | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Satisfactory

- **Variety and delight**
  a. Are circulation and social areas inviting to students?

Yes ☐ No ☐

- **High quality**
  a. Does the quality of the space encourage good behaviour?

Yes ☐ No ☐

  b. Are learning spaces well proportioned and pleasant?

Yes ☐ No ☐

- **The building in use**
  a. Will the building work well in full use?

Yes ☐ No ☐

  b. Do you think if the use of the glazing area on corridor walls and the outdoor courtyards cause disturbance to adjacent class spaces?

Yes ☐ No ☐

Any comments:

7. **Resources**: deploying convincing environmental strategies

Overall satisfaction of the completion Please tick

Unsatisfactory | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Satisfactory

- **Energy and services strategies**

a. Does the whole design help to minimise energy use and carbon emissions?

Yes ☐ No ☐

b. How satisfied were you with the efficiency and convenience of the Building Management System?

Unsatisfactory | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Satisfactory

c. Is there any sustainable technologies? How satisfied were you with their performance in saving energy?

Unsatisfactory | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Satisfactory

Any comments:

---

8. **Feeling safe**: creating a secure and welcoming place

Overall satisfaction of the completion Please tick

Unsatisfactory | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Satisfactory

- **External environment**

a. How satisfied were you with the security strategies with openness

Unsatisfactory | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Satisfactory

- **Internal environment**

a. Are there opportunities for passive surveillance throughout the school?

Yes ☐ No ☐

b. Does the design of toilets, staircases and circulation areas allow for visibility so users feel safe?

Yes ☐ No ☐

Any comments:

Overall satisfaction of the completion Please tick

Unsatisfactory | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Satisfactory

- **Day-to-day flexibility**

a. Does the design provide day-to-day flexibility for different types of learning and teaching?

Yes ☐ No ☐

- **Adaptability**

a. How well does the design allow for future expansion of the school?

Not at all | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Very well

- **Furniture & Equipment**

a. Can a good range of layouts be made using the proposed furniture?

Yes ☐ No ☐

Any comments:

---

10. **Successful whole**: making a design that works in the round.

Overall satisfaction of the completion Please tick

Unsatisfactory | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Satisfactory

- **Appropriateness**

a. Does this design as a whole offer a thoughtful, coherent and convincing response to the key issues of the site and brief?

Yes ☐ No ☐

- **Delight**

a. Will it be a pleasure to work, eat, learn, play, teach and socialise in this school?

Yes ☐ No ☐

- **Timelessness**

a. Is this school set to become a cherished part of its locality?

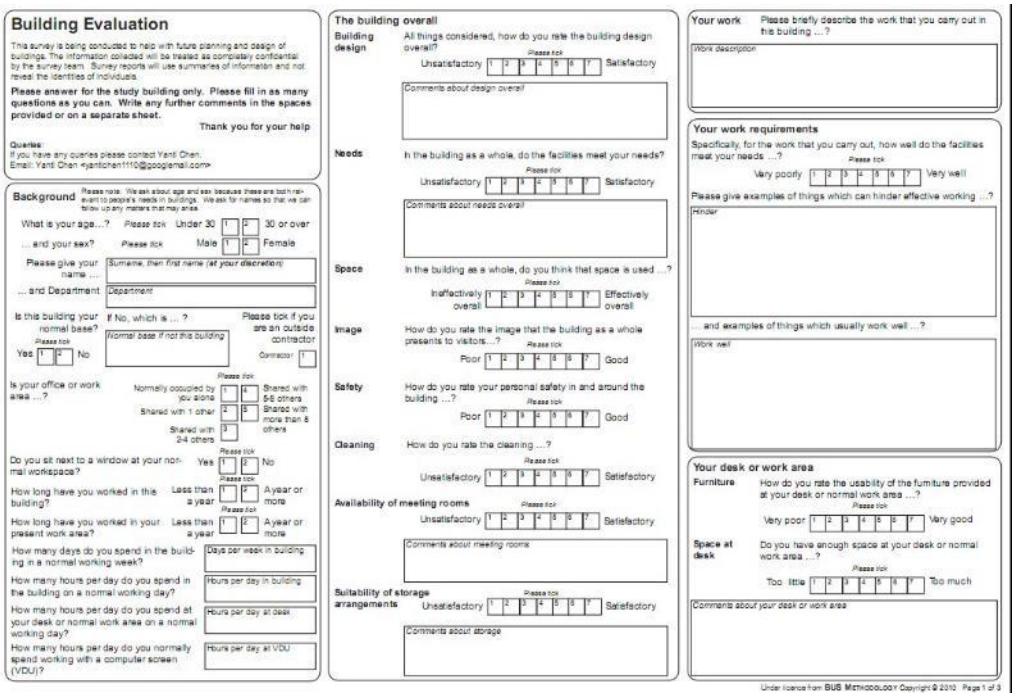
Yes ☐ No ☐

- **Fulfilling user intentions**

a. Does the architectural approach successfully meet the aspirations of the client and community?

Yes ☐ No ☐

- BUS Occupant questionnaires



Building Evaluation

This survey is being conducted to help with future planning and design of buildings. The information collected will be treated as completely confidential by the survey team. Survey reports will use summaries of information and not reveal the identities of individuals.

Please answer for the study building only. Please fill in as many questions as you can. Write any further comments in the spaces provided or on a separate sheet.

Thank you for your help

Queries:
If you have any queries please contact Yanti Chen.
Email: Yanti Chen <yantichen1110@googlemail.com>

Background Please note: We ask about age and sex because these are both relevant to people's needs in buildings. We ask for names so that we can follow up any matters that may arise.

What is your age...? Please tick: Under 30 / 30 or over

... and your sex? Please tick: Male / Female

Please give your name ... Surname, then first name (at your discretion)

... and Department: Department

Is this building your normal base? Please tick: Yes / No

If No, which is ... ? Normal base if not this building

Please tick if you are an outside contractor: Contractor

Is your office or work area ...? Please tick: Normally occupied by you alone / Shared with 1 other / Shared with 2-4 others / Shared with 5-8 others / Shared with more than 8 others

Do you sit next to a window at your normal workspace? Please tick: Yes / No

How long have you worked in this building? Please tick: Less than a year / A year or more

How long have you worked in your present work area? Please tick: Less than a year / A year or more

How many days do you spend in the building in a normal working week? Days per week in building

How many hours per day do you spend in the building on a normal working day? Hours per day in building

How many hours per day do you spend at your desk or normal work area on a normal working day? Hours per day at desk

How many hours per day do you normally spend working with a computer screen (VDU)? Hours per day at VDU

The building overall

Building design All things considered, how do you rate the building design overall? Please tick: Unsatisfactory 1 2 3 4 5 6 7 Satisfactory

Comments about design overall

Needs In the building as a whole, do the facilities meet your needs? Please tick: Unsatisfactory 1 2 3 4 5 6 7 Satisfactory

Comments about needs overall

Space In the building as a whole, do you think that space is used ...? Please tick: Ineffectively overall 1 2 3 4 5 6 7 Effectively overall

Image How do you rate the image that the building as a whole presents to visitors...? Please tick: Poor 1 2 3 4 5 6 7 Good

Safety How do you rate your personal safety in and around the building ...? Please tick: Poor 1 2 3 4 5 6 7 Good

Cleaning How do you rate the cleaning ...? Please tick: Unsatisfactory 1 2 3 4 5 6 7 Satisfactory

Availability of meeting rooms Please tick: Unsatisfactory 1 2 3 4 5 6 7 Satisfactory

Comments about meeting rooms

Suitability of storage arrangements Please tick: Unsatisfactory 1 2 3 4 5 6 7 Satisfactory

Comments about storage

Your work Please briefly describe the work that you carry out in this building ...?

Work description

Your work requirements

Specifically, for the work that you carry out, how well do the facilities meet your needs ...? Please tick: Very poorly 1 2 3 4 5 6 7 Very well

Please give examples of things which can hinder effective working ...?

Hinder

... and examples of things which usually work well ...?

Work well

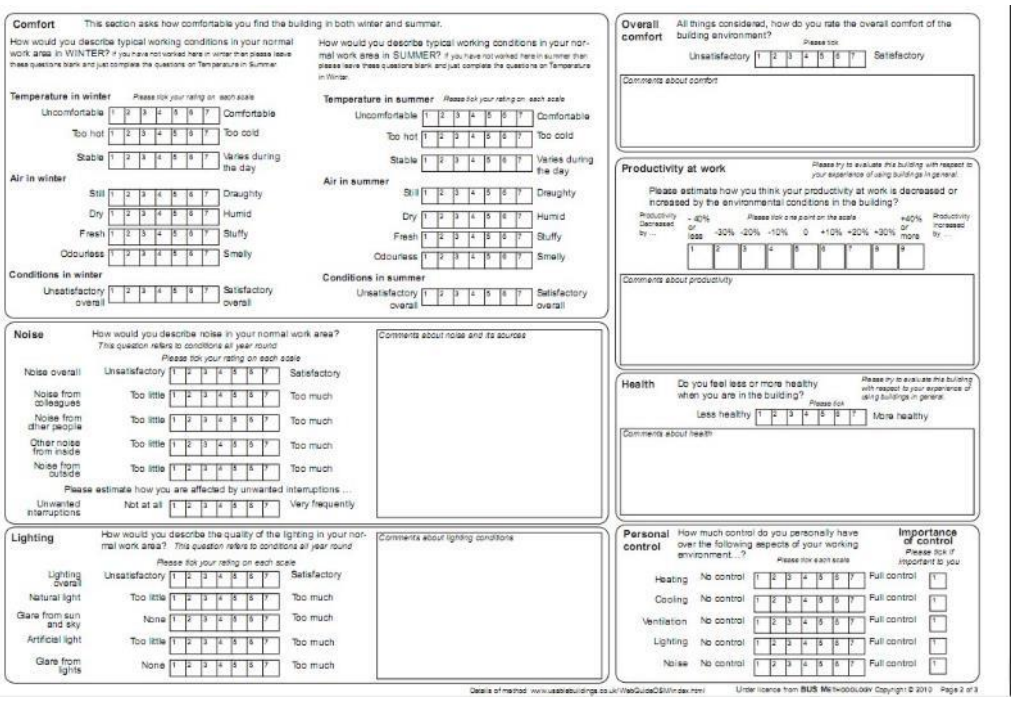
Your desk or work area

Furniture How do you rate the usability of the furniture provided at your desk or normal work area ...? Please tick: Very poor 1 2 3 4 5 6 7 Very good

Space at desk Do you have enough space at your desk or normal work area ...? Please tick: Too little 1 2 3 4 5 6 7 Too much

Comments about your desk or work area

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Comfort This section asks how comfortable you find the building in both winter and summer.

How would you describe typical working conditions in your normal work area in WINTER? If you have not worked here in winter then please leave these questions blank and just complete the questions on Temperature in Summer.

Temperature in winter Please tick your rating on each scale

Uncomfortable 1 2 3 4 5 6 7 Comfortable

Too hot 1 2 3 4 5 6 7 Too cold

Stable 1 2 3 4 5 6 7 Varies during the day

Air in winter

Still 1 2 3 4 5 6 7 Draughty

Dry 1 2 3 4 5 6 7 Humid

Fresh 1 2 3 4 5 6 7 Stuffy

Odourless 1 2 3 4 5 6 7 Smelly

Conditions in winter

Unsatisfactory overall 1 2 3 4 5 6 7 Satisfactory overall

How would you describe typical working conditions in your normal work area in SUMMER? If you have not worked here in summer then please leave these questions blank and just complete the questions on Temperature in Winter.

Temperature in summer Please tick your rating on each scale

Uncomfortable 1 2 3 4 5 6 7 Comfortable

Too hot 1 2 3 4 5 6 7 Too cold

Stable 1 2 3 4 5 6 7 Varies during the day

Air in summer

Still 1 2 3 4 5 6 7 Draughty

Dry 1 2 3 4 5 6 7 Humid

Fresh 1 2 3 4 5 6 7 Stuffy

Odourless 1 2 3 4 5 6 7 Smelly

Conditions in summer

Unsatisfactory overall 1 2 3 4 5 6 7 Satisfactory overall

Noise How would you describe noise in your normal work area? This question refers to conditions all year round. Please tick your rating on each scale

Noise overall: Unsatisfactory 1 2 3 4 5 6 7 Satisfactory

Noise from colleagues: Too little 1 2 3 4 5 6 7 Too much

Noise from other people: Too little 1 2 3 4 5 6 7 Too much

Other noise from inside: Too little 1 2 3 4 5 6 7 Too much

Noise from outside: Too little 1 2 3 4 5 6 7 Too much

Please estimate how you are affected by unwanted interruptions ...

Unwanted interruptions: Not at all 1 2 3 4 5 6 7 Very frequently

Comments about noise and its sources

Lighting How would you describe the quality of the lighting in your normal work area? This question refers to conditions all year round. Please tick your rating on each scale

Lighting overall: Unsatisfactory 1 2 3 4 5 6 7 Satisfactory

Natural light: Too little 1 2 3 4 5 6 7 Too much

Glare from sun and sky: None 1 2 3 4 5 6 7 Too much

Artificial light: Too little 1 2 3 4 5 6 7 Too much

Glare from lights: None 1 2 3 4 5 6 7 Too much

Comments about lighting conditions

Overall comfort All things considered, how do you rate the overall comfort of the building environment? Please tick: Unsatisfactory 1 2 3 4 5 6 7 Satisfactory

Comments about comfort

Productivity at work Please try to evaluate this building with respect to your experience of using buildings in general.

Please estimate how you think your productivity at work is decreased or increased by the environmental conditions in the building?

Productivity Decreased by ... / Please tick a no point on the scale / Productivity Increased by ...

- 40% or less / -30% / -20% / -10% / 0 / +10% / +20% / +30% / +40% or more

1 2 3 4 5 6 7 8 9

Comments about productivity

Health Do you feel less or more healthy when you are in the building? Please tick: Less healthy 1 2 3 4 5 6 7 More healthy

Please try to evaluate this building with respect to your experience of using buildings in general.

Comments about health

Personal control How much control do you personally have over the following aspects of your working environment...? Please tick each scale

Importance of control Please tick if important to you

Heating: No control 1 2 3 4 5 6 7 Full control 1

Cooling: No control 1 2 3 4 5 6 7 Full control 1

Ventilation: No control 1 2 3 4 5 6 7 Full control 1

Lighting: No control 1 2 3 4 5 6 7 Full control 1

Noise: No control 1 2 3 4 5 6 7 Full control 1

Details of method: www.usablebuildings.co.uk/WebGuideOS/Index.html Under licence from BUS Methodology Copyright © 2010

Appendix 3: School design information

- Design intent of the schools studied

Wellstead Primary School	• Creating a strong sense of place and community identity • Allowing the community in but providing a secure and safe environment • Inspiring learning and attendance • Encouraging development of a child's sociability and well-being • Offering longevity and attractive environments with adaptable delightful structure • Being energy efficient and minimising carbon emissions
Sandal Magna Primary School	• To produce a new identity for the school with positive street presence • To maintain a sense of history and memory • To provide a welcoming building for students, parents and teachers • Site security and robustness of materials • Scale and relationship of new building to the site • Flexibility of spaces within the new building • Provision of a variety of play spaces • Importance of a community space • Importance of energy efficiency and sustainability
St Luke's C.E. Primary School	- To minimise energy consumption in terms of heating and electricity loads while maintaining an inspiring and comfortable learning/working environment for all the school users.
Minster School	- To create an atmosphere of caring and purpose derived from a commitment to moral and religious principles; to showcase

	the Humanities and Music specialist status; - To encourage and develop leadership and active citizenship within the school and wider community - to allow accessible facilities for the wider community; - To develop and maintain excellence in teaching and learning, providing a variety of adaptable ICT-rich spaces, ease of movement and passive supervision without overt control; - To enhance the relationship between students and the school staff, and also with the wider community; - To be integrated into the surrounding landscape maximising opportunities for external education; - To maximise opportunities of sustainability in the school and to minimise carbon emissions of the school.
Chelsea Academy	• To provide a "*much-needed*" secondary school in the Brough bringing the two groups together (Architecture Today, 2010). • To respond to the constraints posed by the natures of this inner-city site, and to provide "*identity, flexibility and an inspiring learning environment*" (FCBs, 2011). • To reduce energy use and carbon emissions of the school.

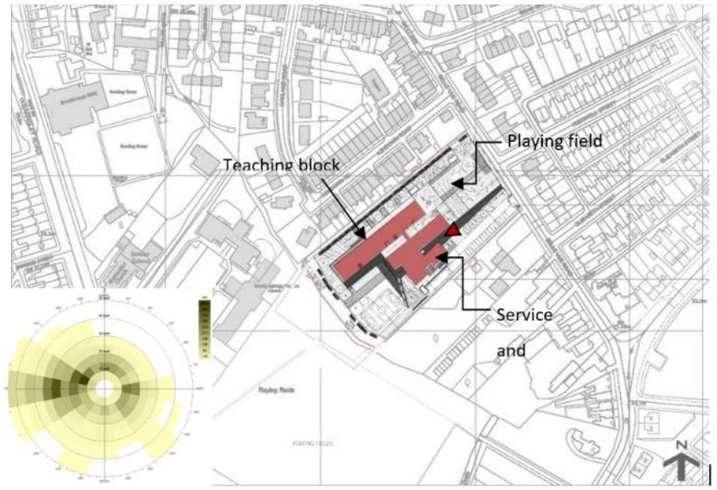
- Site of the schools studied

Wellstead Primary School	

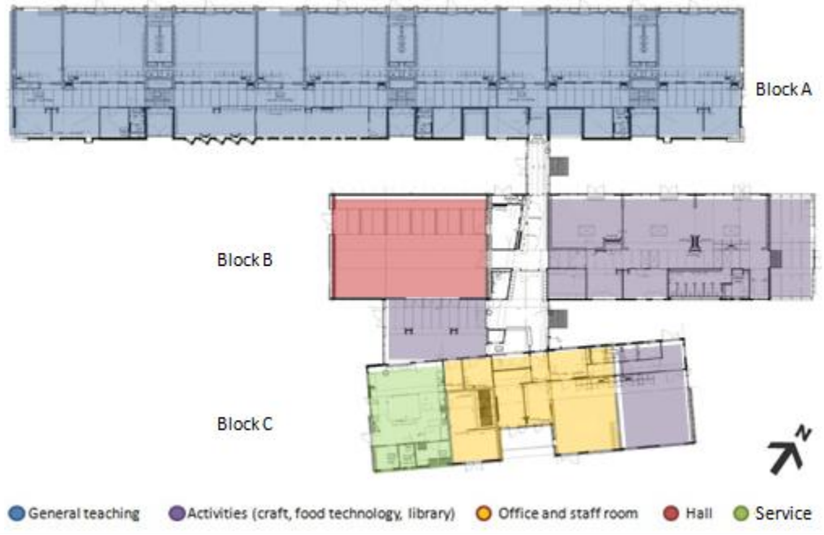
Sandal Magna Primary School	
St Luke's C.E. Primary School	
Minster School	
Chelsea Academy	

- Design documentations of School B

Site



Plans



School images

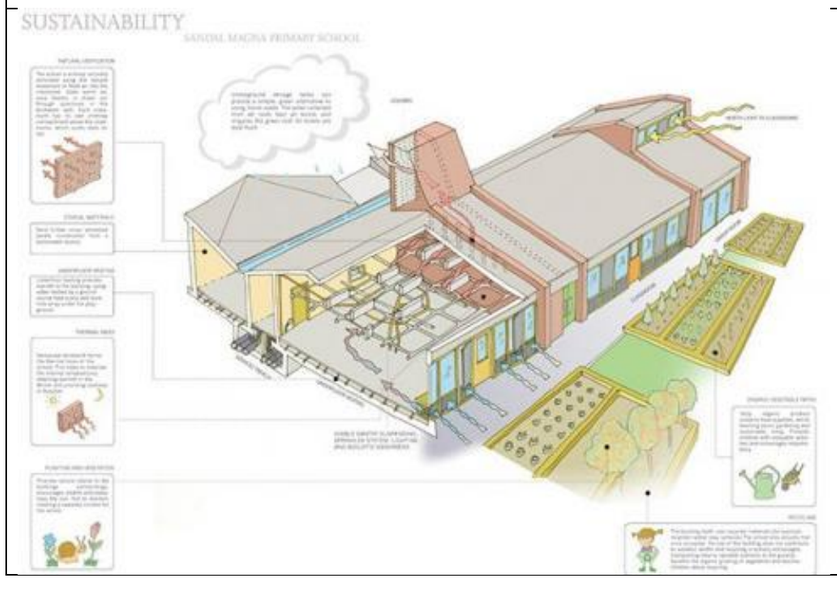
Classroom



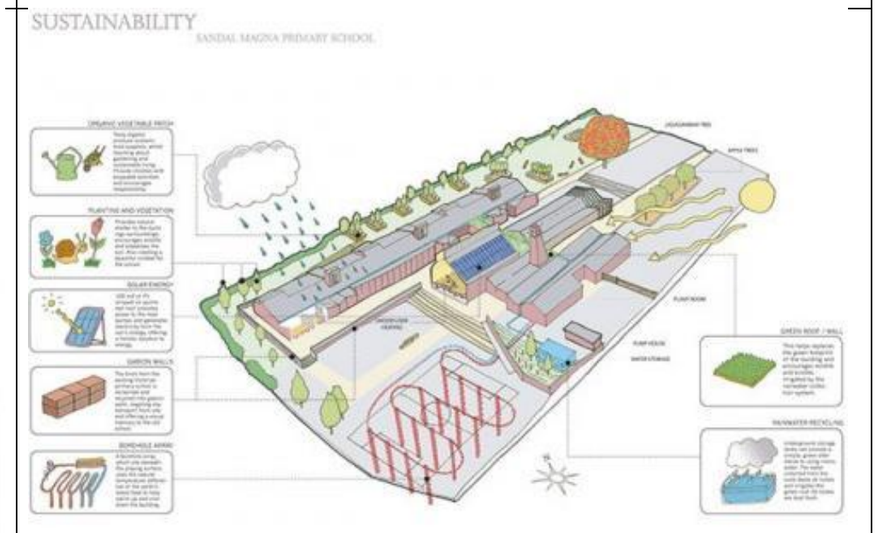
Staff room



Environmental strategies



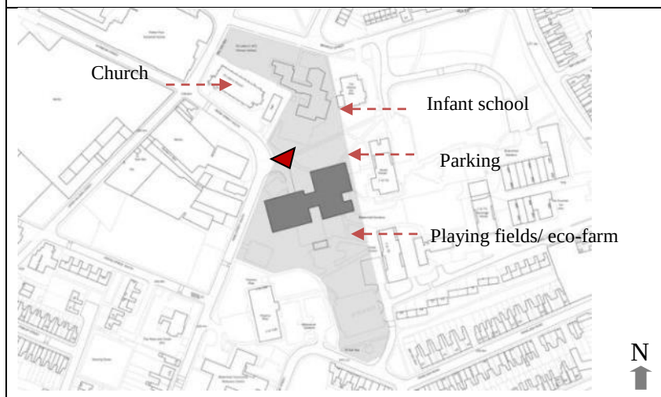
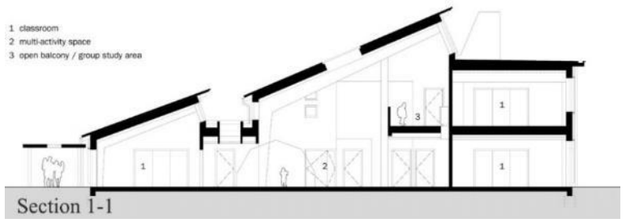
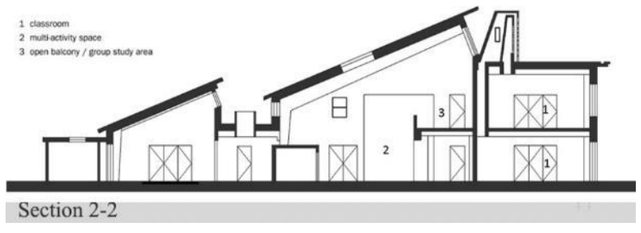
Sustainable technologies



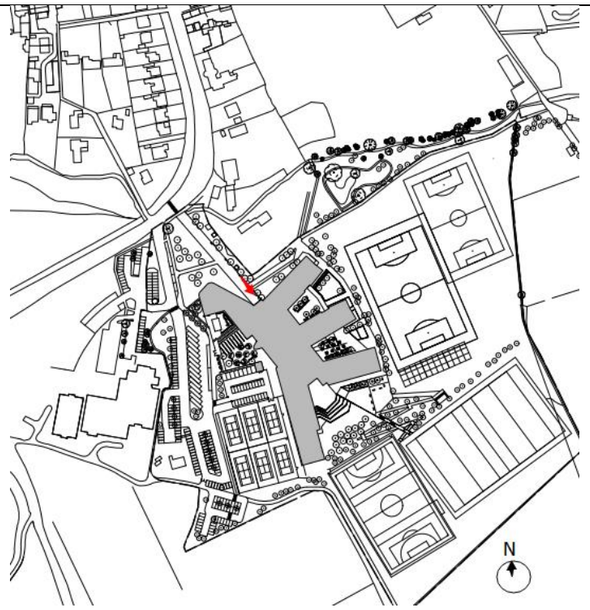
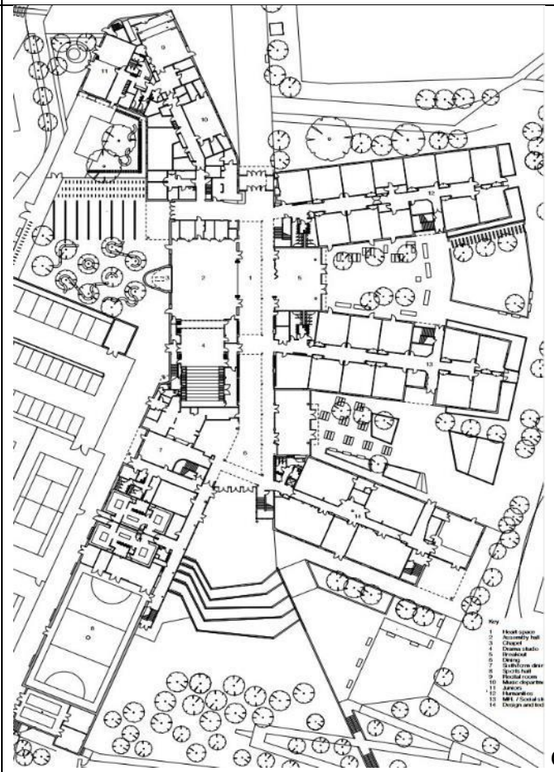
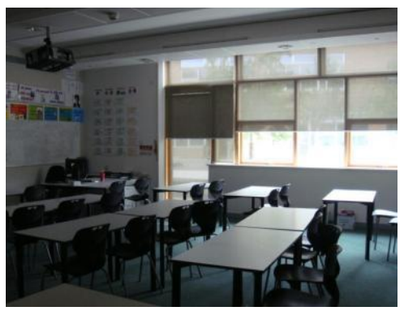
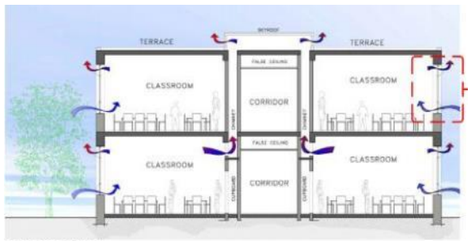
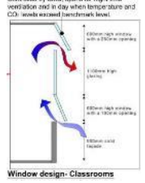
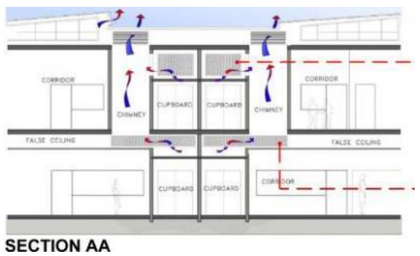
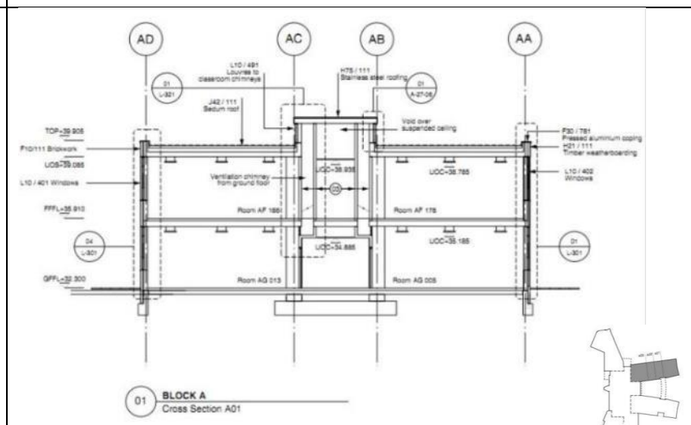
Main materials – local bricks and timber



- Design documentations of School C

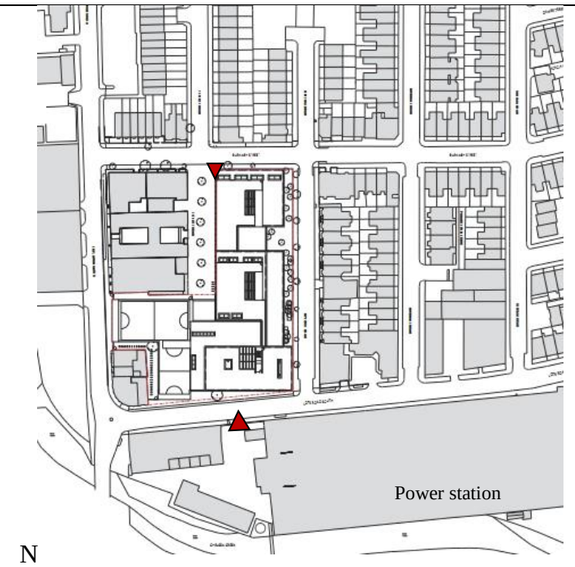
Site	Plans	School images
		Main entrance  Northern elevation  Southern classroom (GF)  Atrium 
Sections   		

- Design documentations of School D

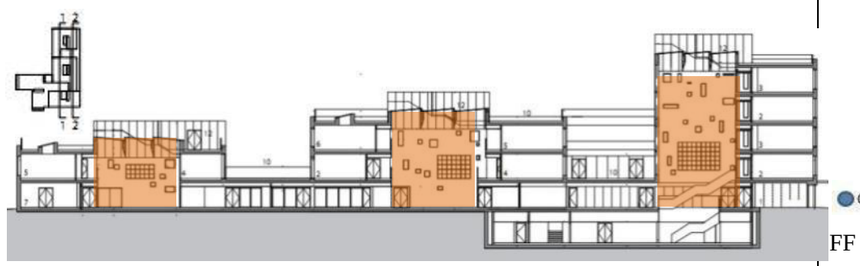
Site plan	Plans	Images
	 GF	 Central ‘street’  Southern classroom  Northern classroom 
Natural ventilation  SECTION ZZ  Window design- Classrooms  SECTION AA 	 01 BLOCK A Cross Section A01	

- Design documentations of School E

Site plan



Section



Plans



Images



Atria



Western classroom



Air inlet in a classroom



Appendix 4: Simulation-related documents

1. School B

Table 0-1: Site shading analysis for School B.

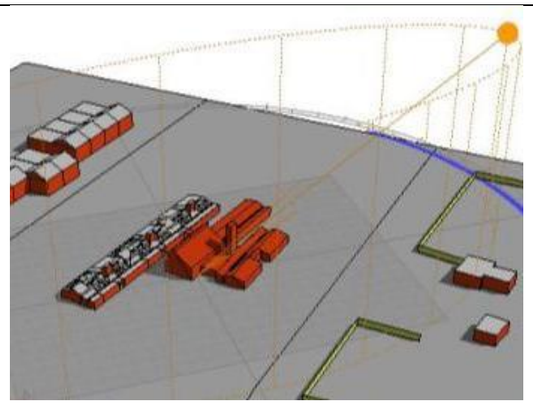
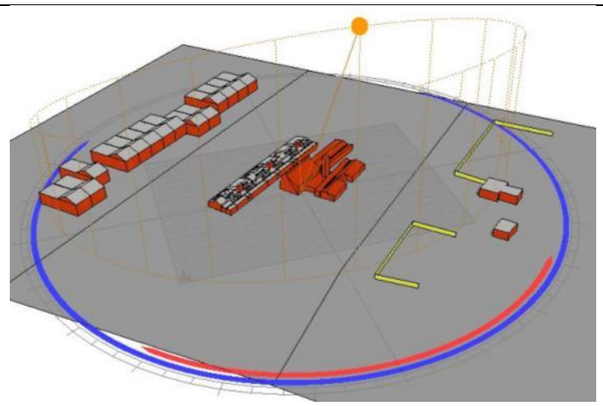
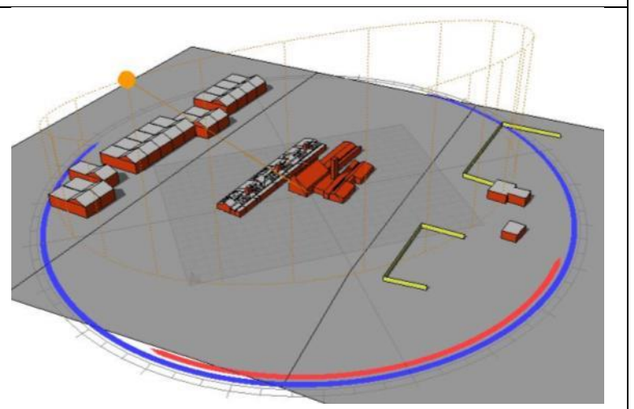
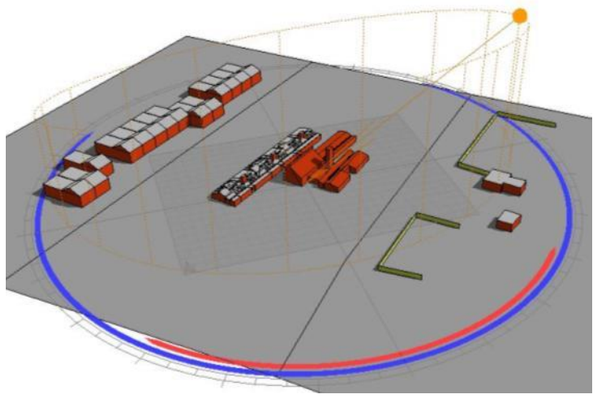
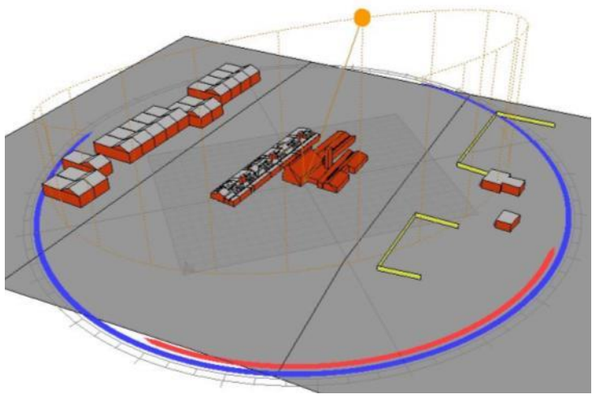
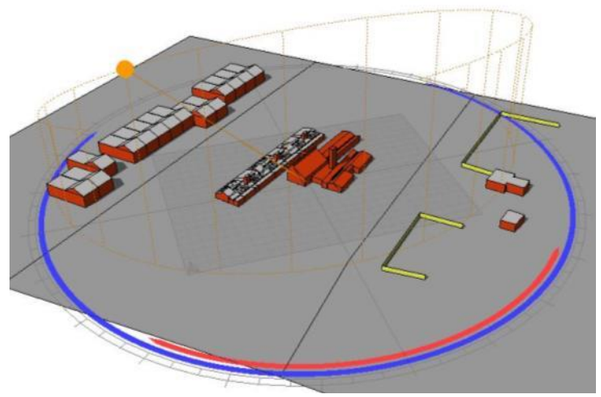
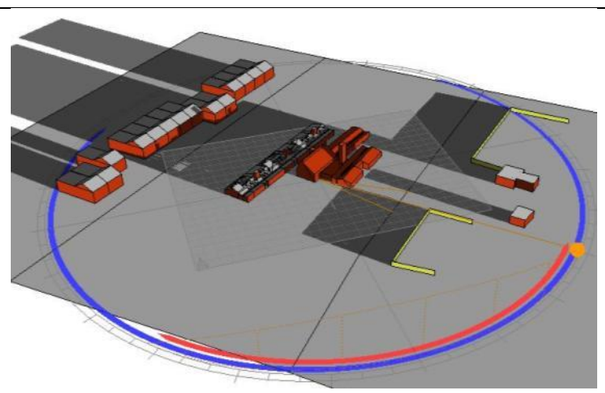
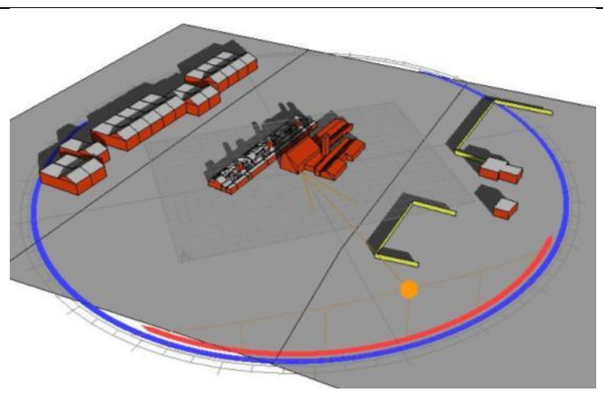
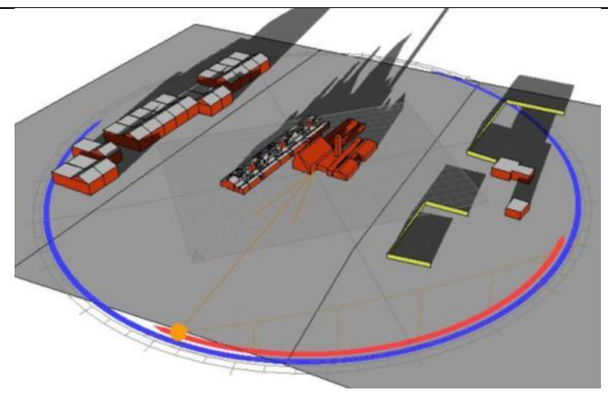
	9:00 a.m.	12:00 o'clock, noon	15:00 p.m.
Summer solstice			
Equinox			
Winter solstice			

Table 0-2: Fields of vision in the classroom (school B) at the summer solstice, the equinox, and the winter solstice at 9:00 a.m., 12:00 o'clock, noon and 15:00 p.m. (Source: Radiance)

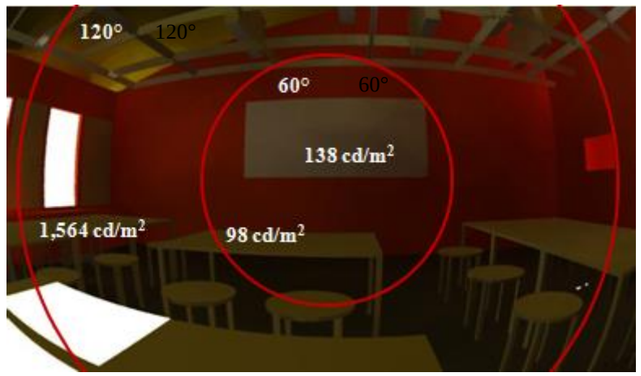
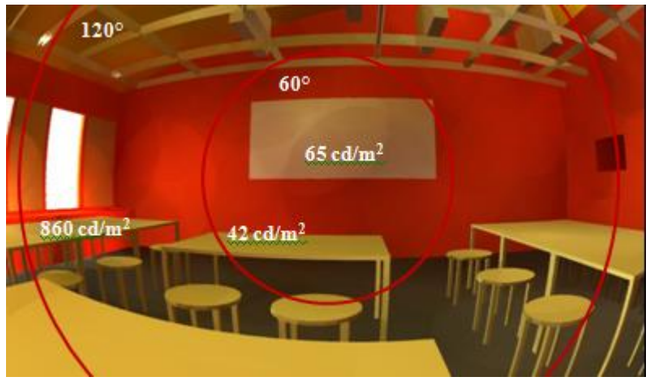
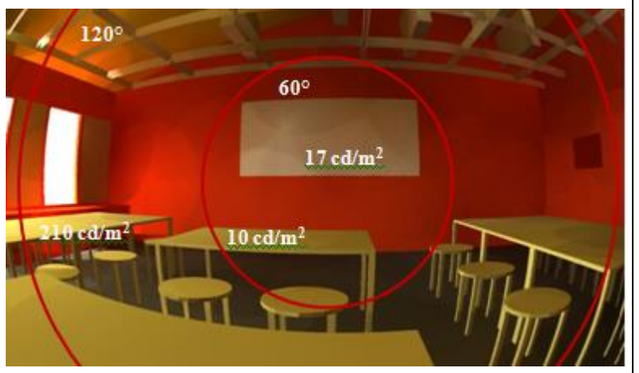
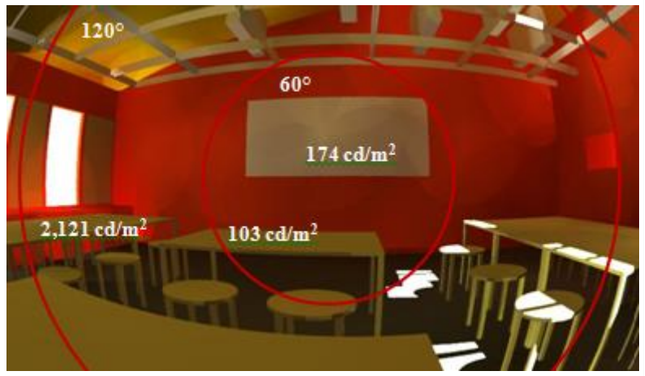
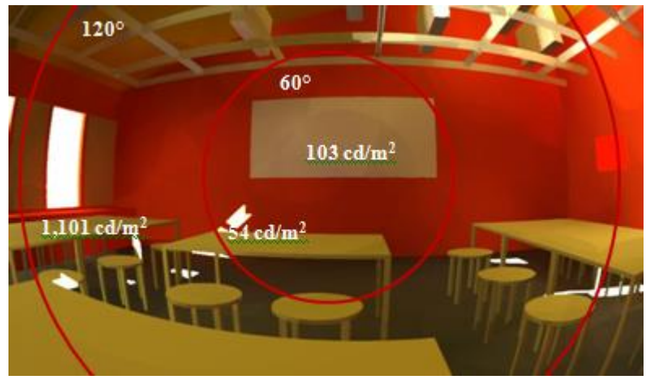
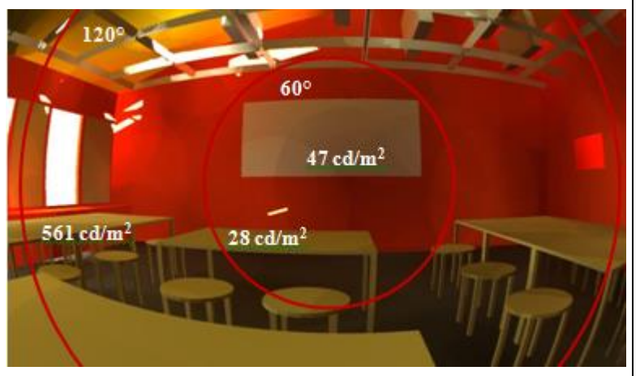
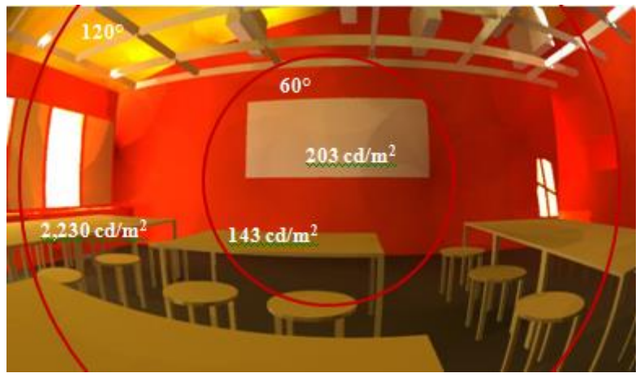
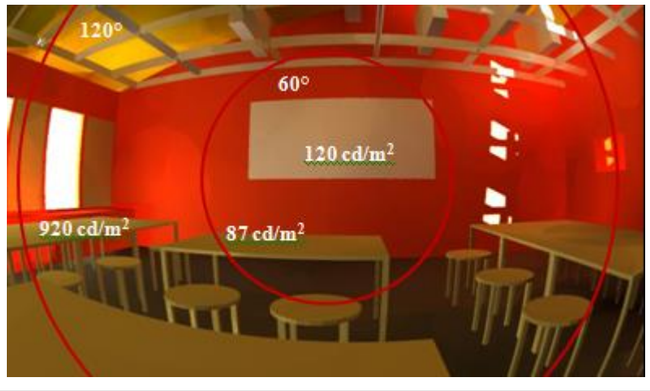
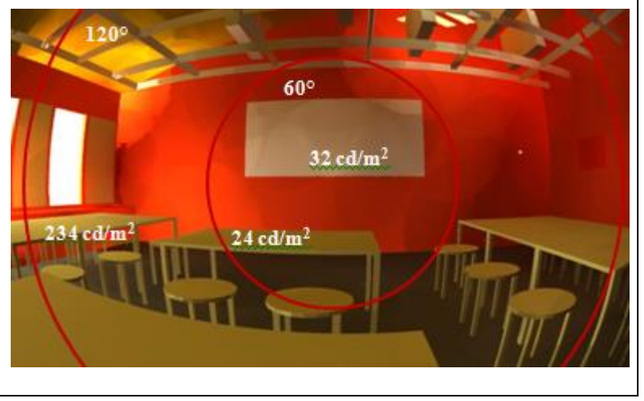
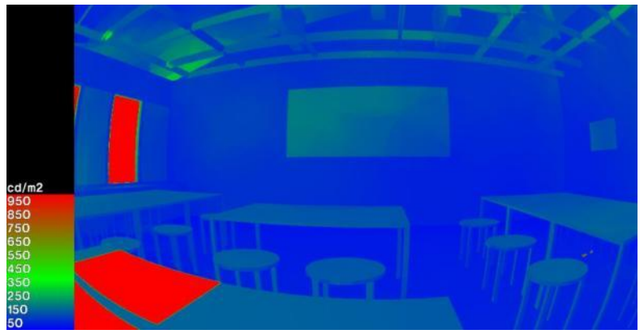
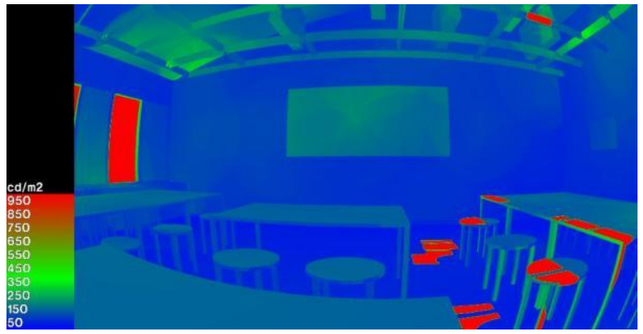
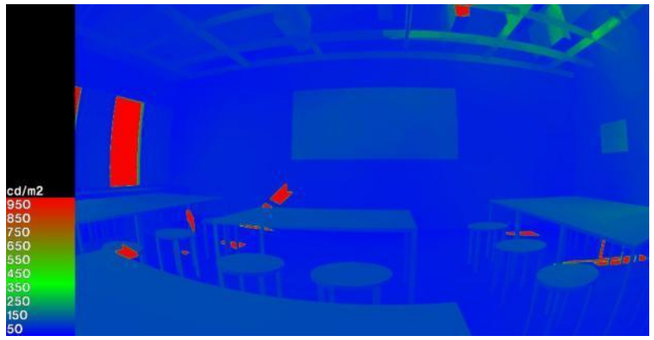
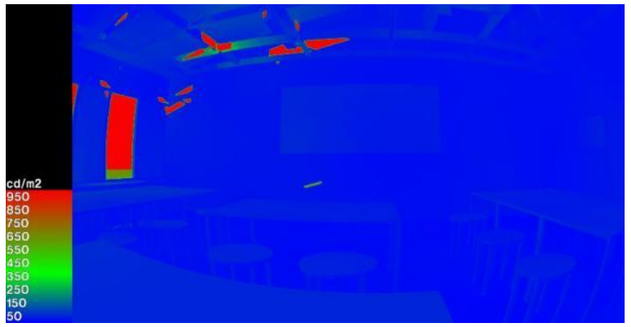
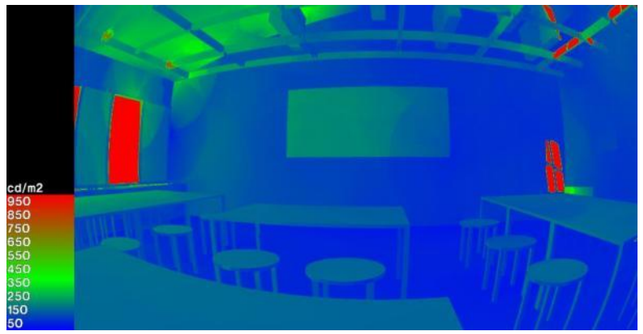
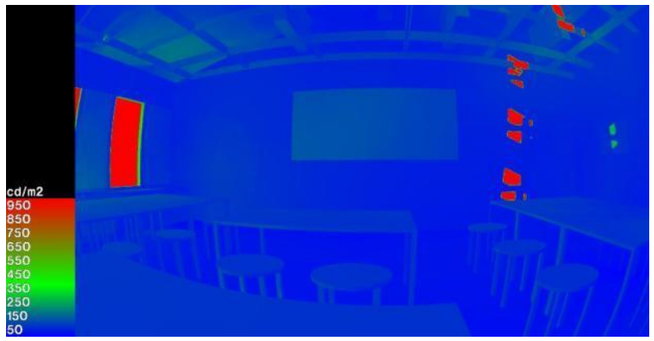
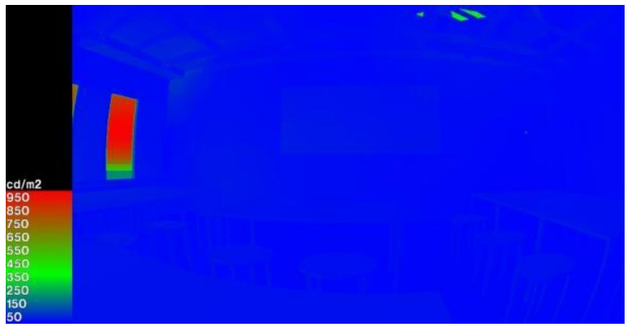
	Summer solstice	Equinox	Winter solstice
9:00 a.m.			
12:00 o'clock, noon			
15:00 p.m.			

Table 0-3: Corresponding false colour maps of internal luminance of the classroom in School C. (Source: Radiance)

	Summer solstice	Equinox	Winter solstice
9:00 a.m.			
12:00 o'clock, noon			
15:00 p.m.			

2. School C

Table 0-4: 3D graphs of DA distributions in the selected classrooms in school C.

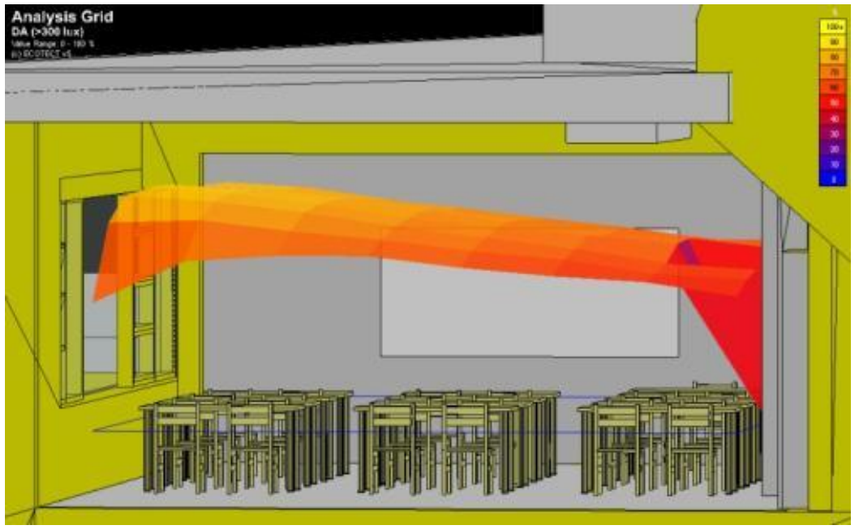
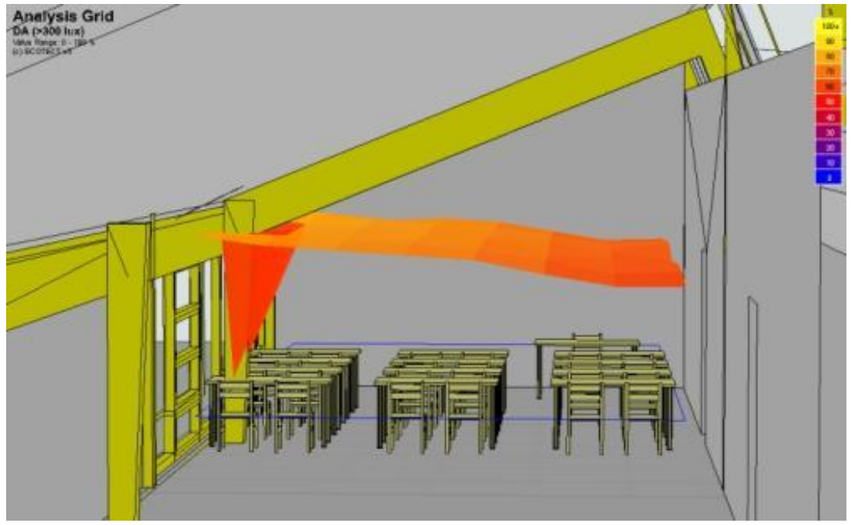
	DA_{300}
Northern classroom $sDA_{300/50\%}$: 95%	
Southern classroom $sDA_{300/50\%}$: 99%	

Table 0-5: Fields of vision in the southern classroom (school C) at the summer solstice, the equinox, and the winter solstice at 9:00 a.m., 12 o'clock noon and 15:00 p.m. (Source: Radiance).

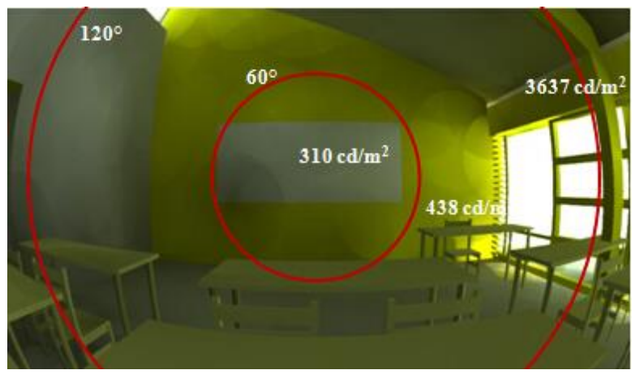
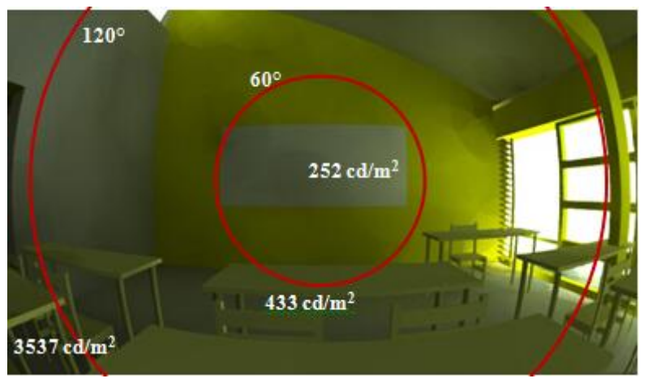
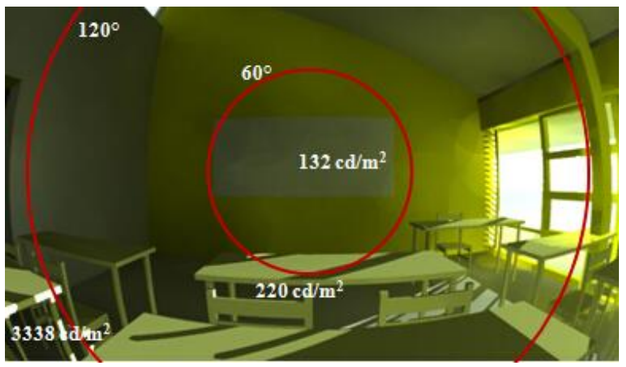
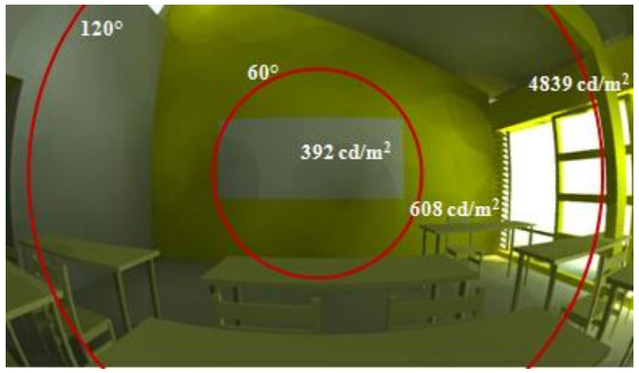
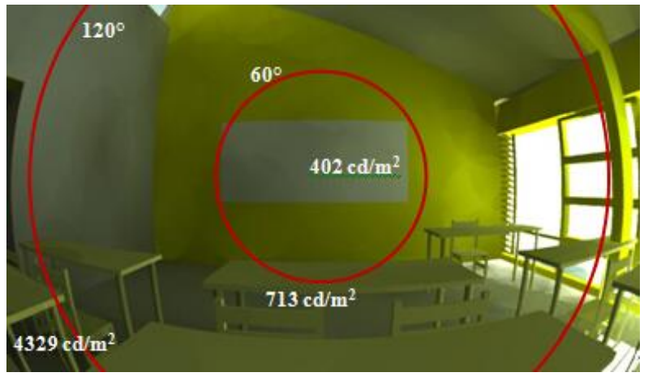
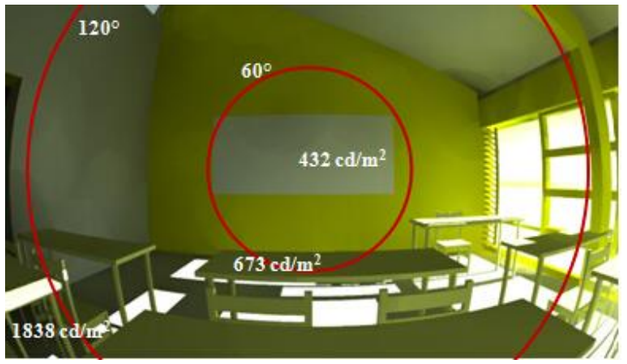
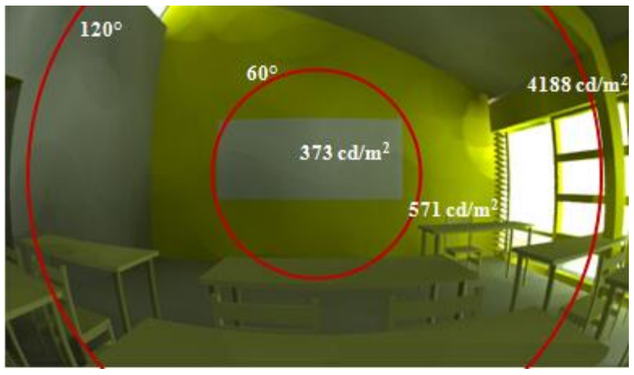
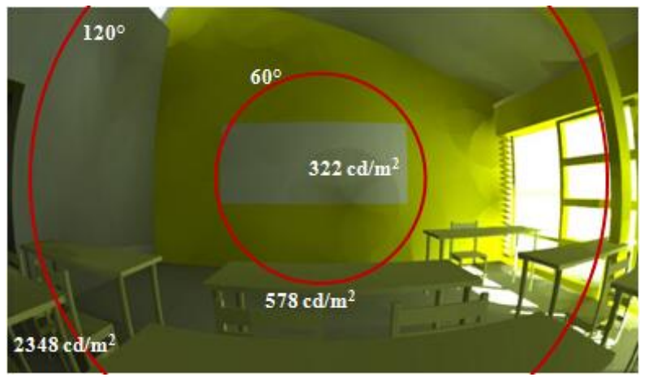
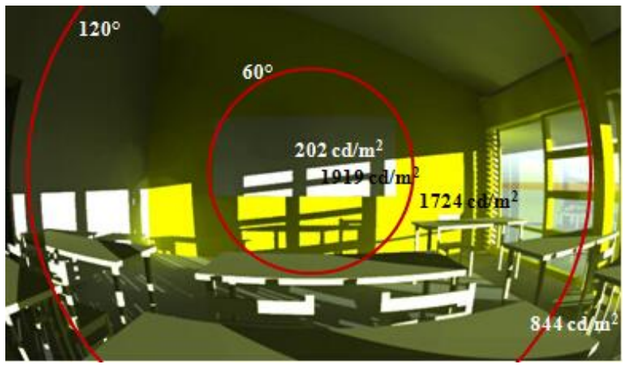
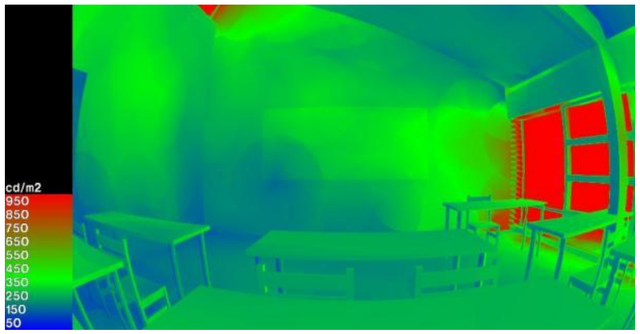
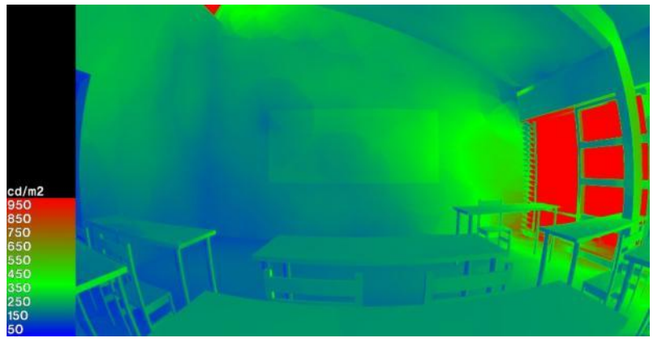
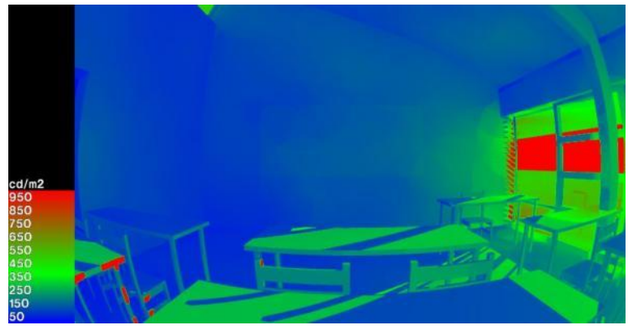
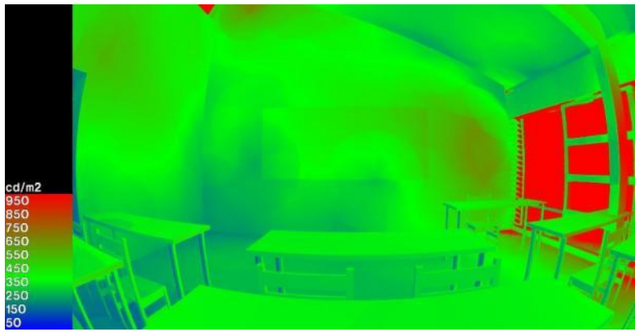
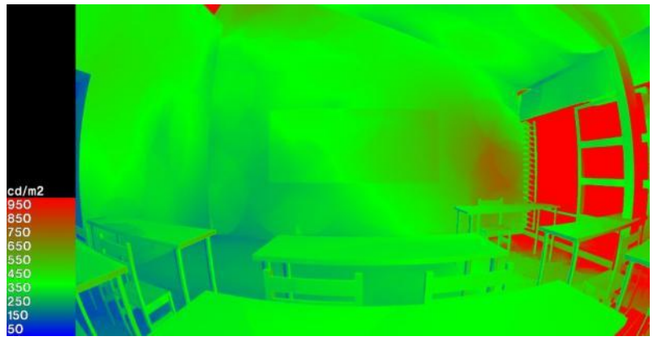
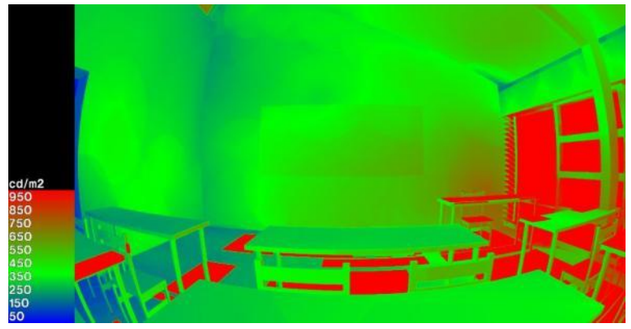
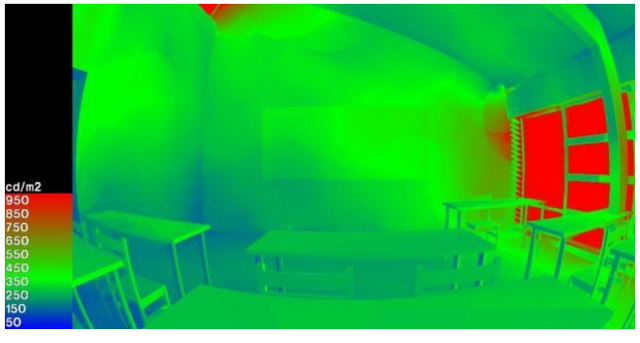
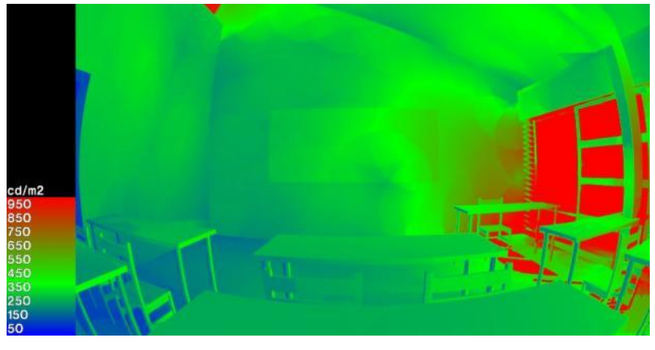
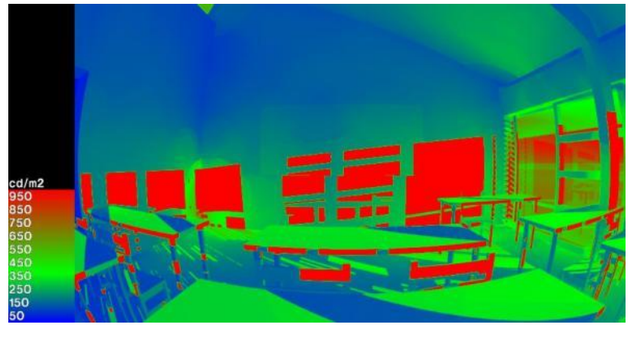
	Summer solstice	Equinox	Winter solstice
9:00 a.m.			
12:00 o'clock, noon			
3 p.m.			

Table 0-6: Corresponding false colour maps of internal luminance of the southern classroom in school C (Source: Radiance).

	Summer solstice	Equinox	Winter solstice
9:00 a.m.			
12:00 o'clock, noon			
15:00 p.m.			

3. School D

Table 0-7: Site shading analysis of school D.

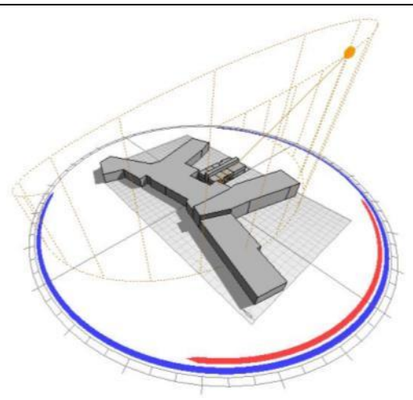
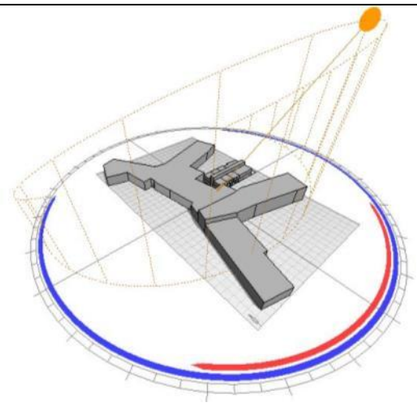
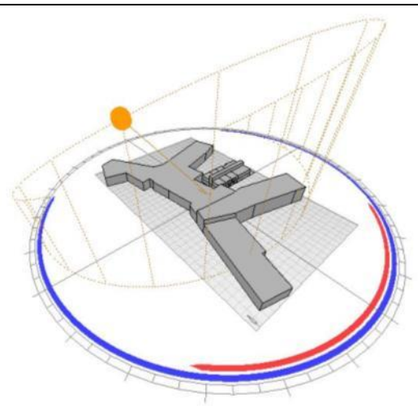
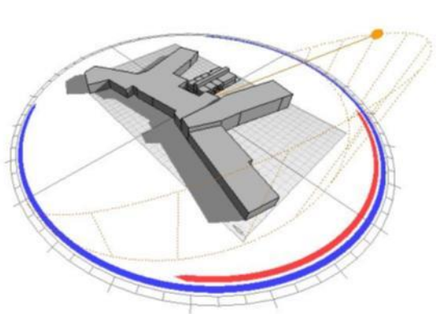
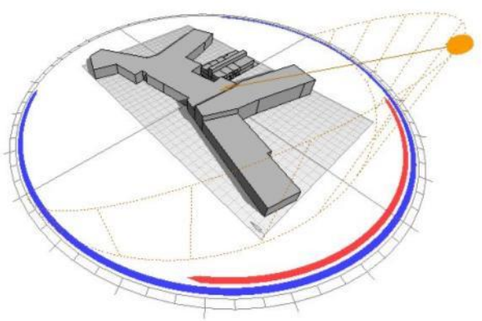
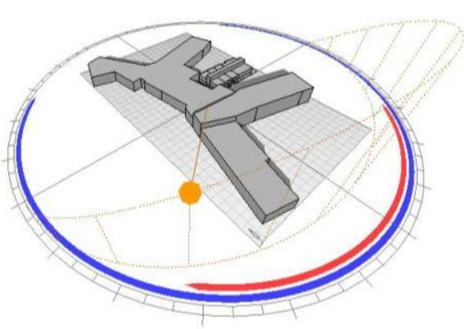
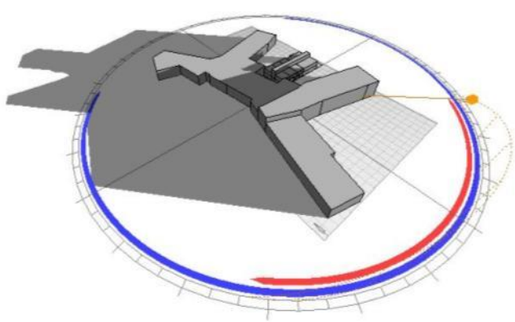
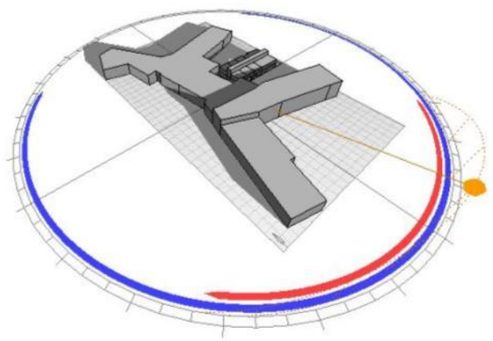
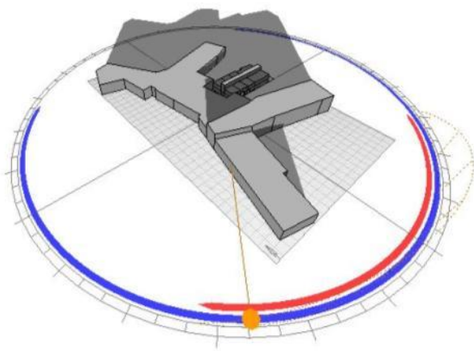
	9:00 a.m.	12:00 o'clock, noon	15:00 p.m.
Summer solstice			
Equinox			
Winter solstice			

Table 0-8: 3D graphs of UDI metrics in the specified classrooms in school D.

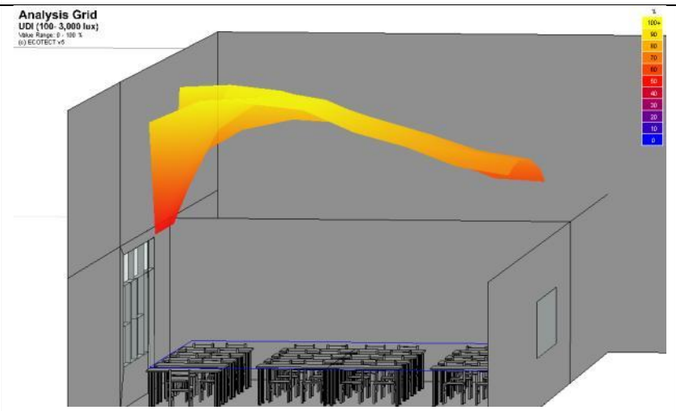
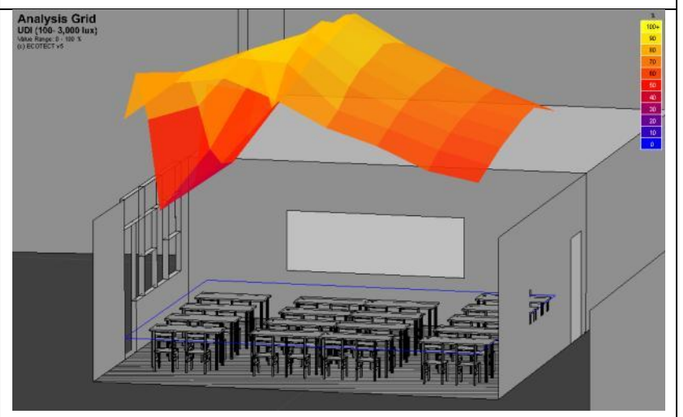
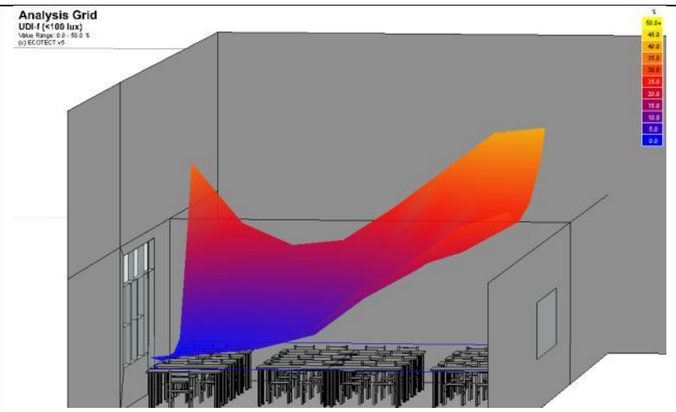
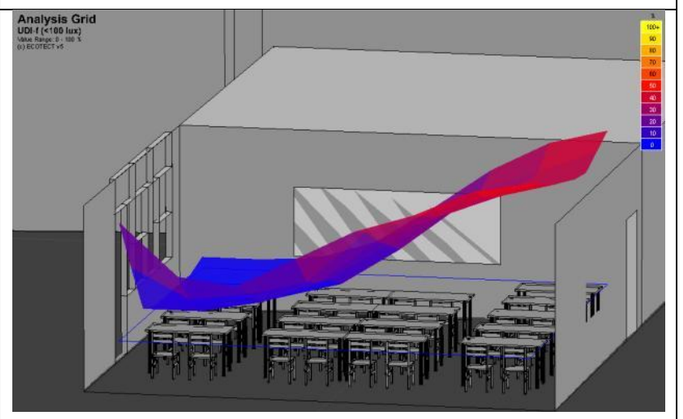
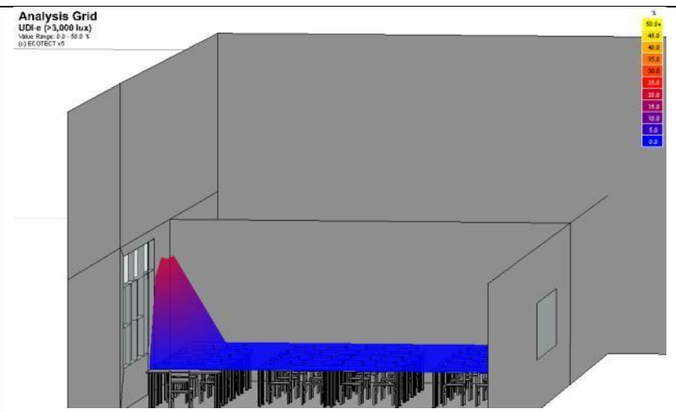
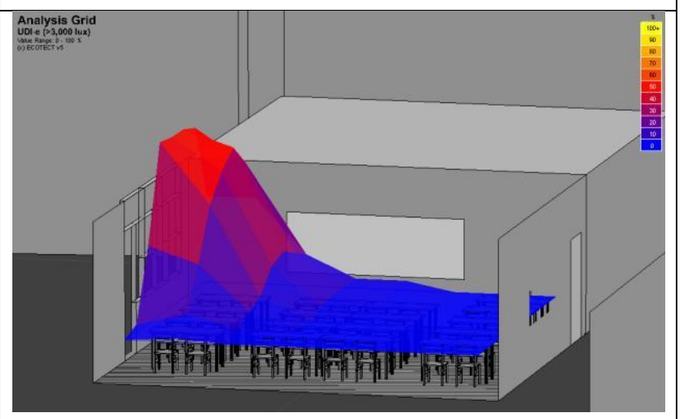
	Northern classroom	Southern classroom
UDI (100-3,000 lux)		
UDI-f (<100 lux)		
UDI-e (> 3,000 lux)		

Table 0-9: Fields of vision in the southern classroom (school D) at the summer solstice, the equinox, and the winter solstice at 9:00 a.m., 12 o'clock, noon and 15:00 p.m. (Source: Radiance)

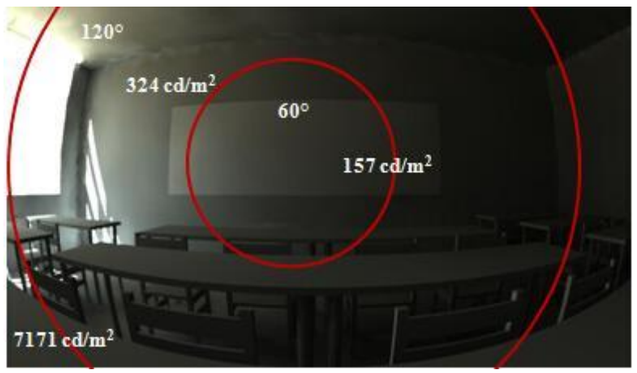
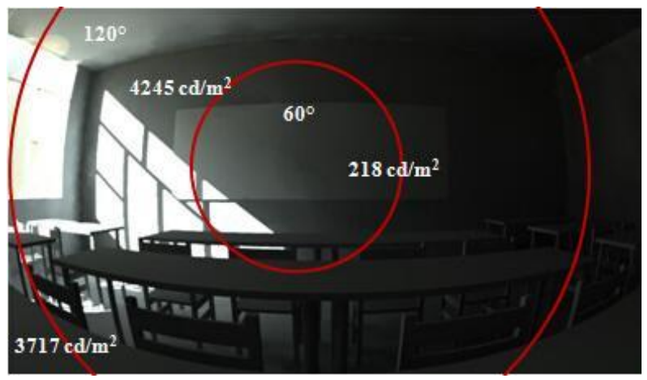
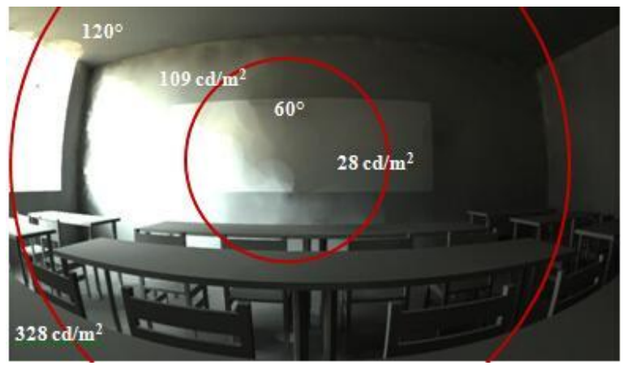
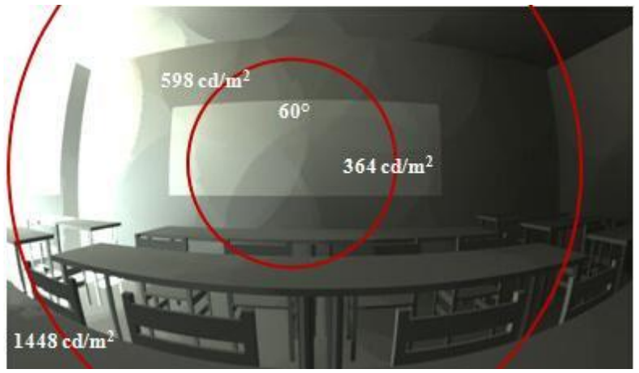
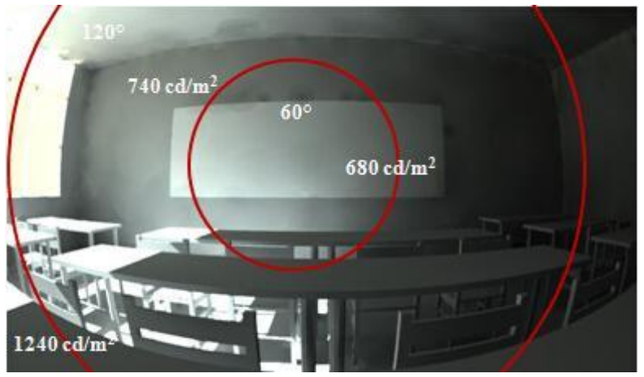
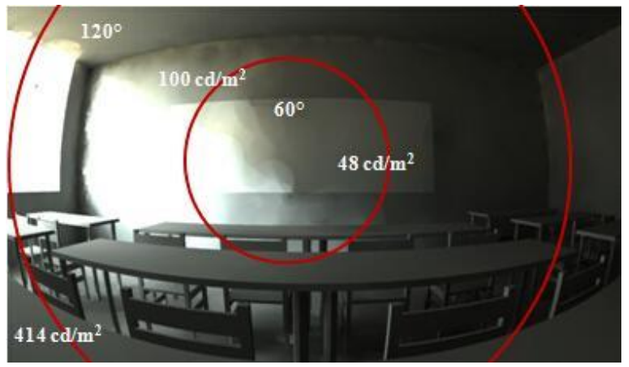
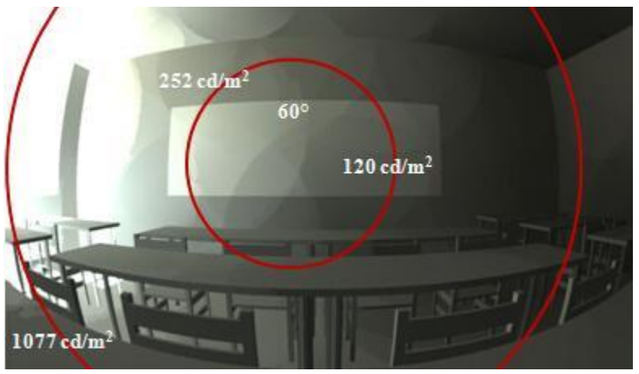
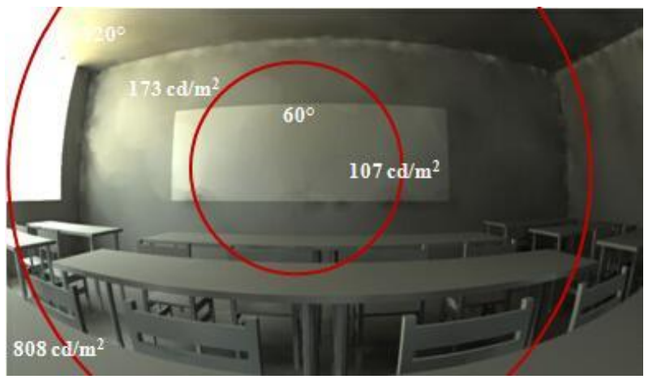
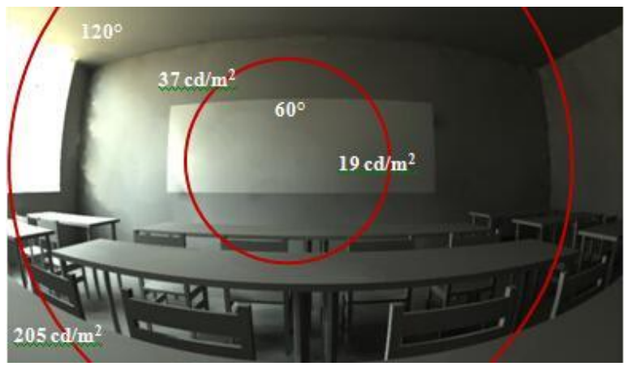
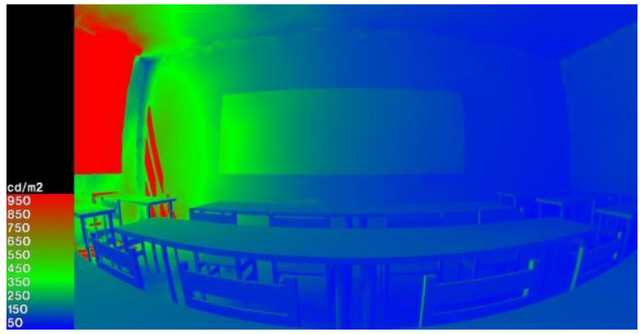
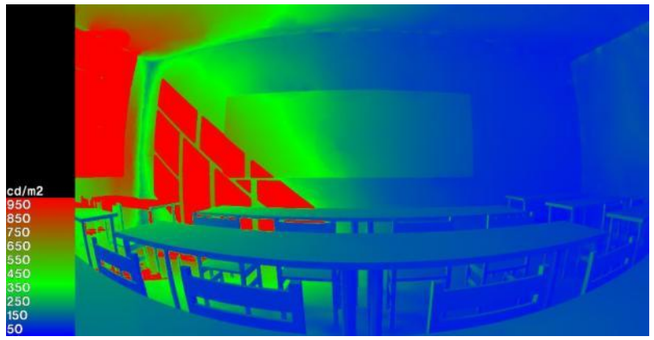
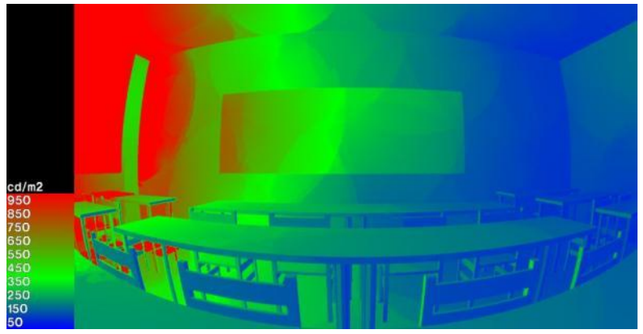
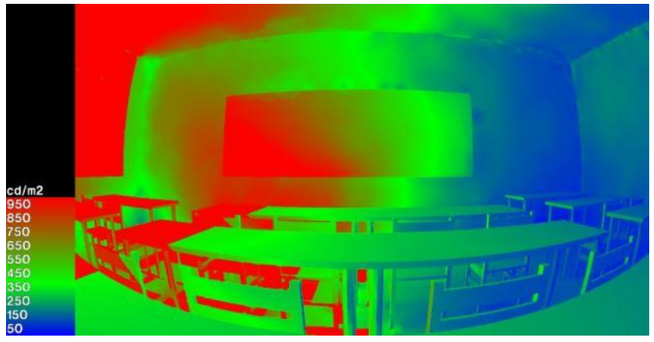
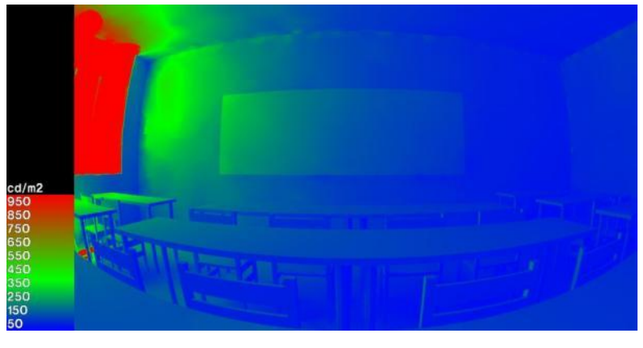
	Summer solstice	Equinox	Winter solstice
9:00 a.m.			
12:00 o'clock, noon			
15:00 p.m.			

Table 0-10: Corresponding false colour maps of internal luminance of the southern classroom in school D (Source: Radiance).

	Summer solstice	Equinox	Winter solstice
9:00 a.m.			
12:00 o'clock, noon			
15:00 p.m.			

4. School E

Table 0-11: Comparison of DA_{300} and $sDA_{300/50\%}$ of the four classrooms in School E.

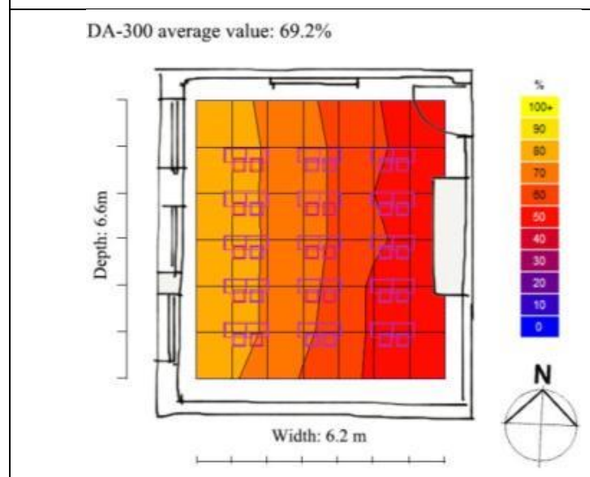
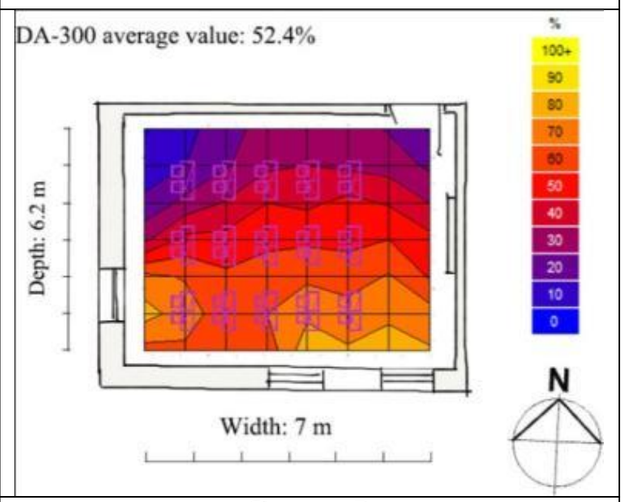
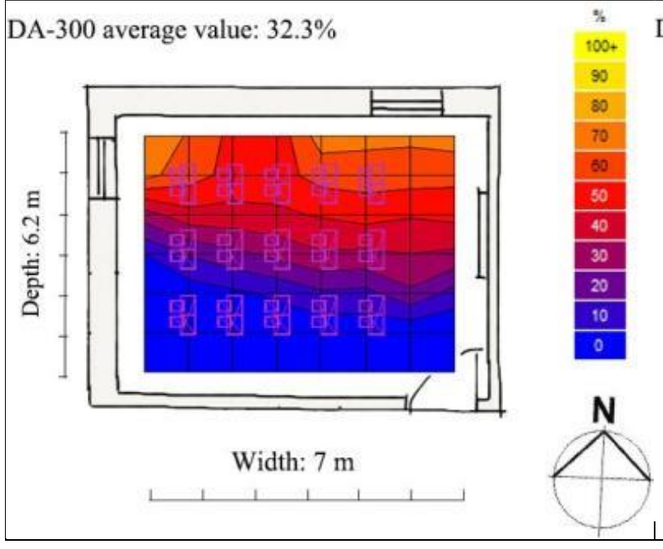
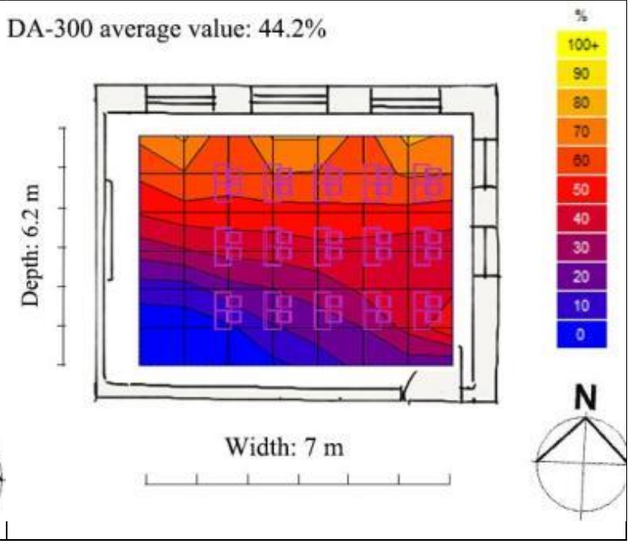
Classroom A $sDA_{300/50\%}$: 100%	Classroom B $sDA_{300/50\%}$: 50.5%
	
Classroom C $sDA_{300/50\%}$: 35.7%	Classroom D $sDA_{300/50\%}$: 44.6%
	

Table 0-12: UDI indices of the four classrooms selected in school E.

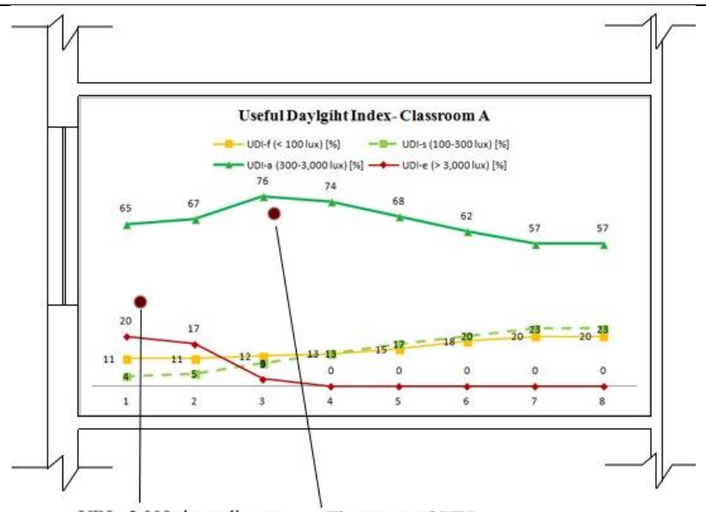
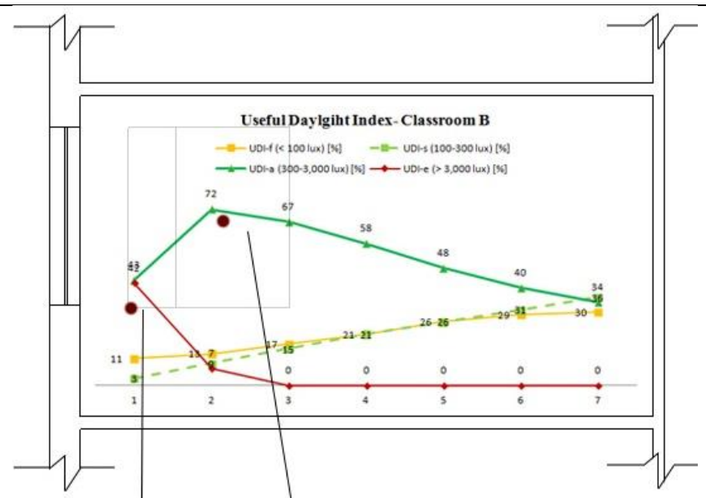
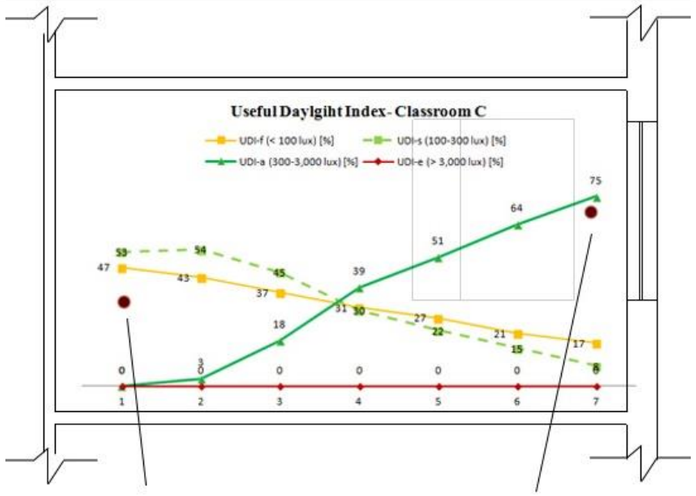
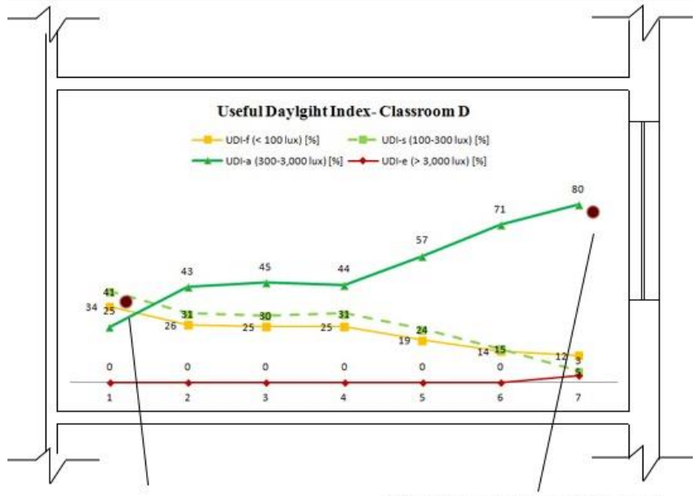
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<tr><td></td><td colspan="2">Classroom A (western classroom) - Average UDI (100- 3,000) : 80%</td><td colspan="2">Classroom B (southern classroom)- Average UDI (100- 3,000) : 72%</td></tr>
<tr><td>UDI metrics</td><td>
</td><td>Average UDI-f: 15%
Average UDI-s: 14.25%
Average UDI-a: 65.75%
Average UDI-e: 5%</td><td>
</td><td>Average UDI-f: 21%
Average UDI-s: 20%
Average UDI-a: 52%
Average UDI-e: 7%</td></tr>
<tr><td></td><td colspan="2">Classroom C (northern classroom)- Average UDI (100- 3,000): 68.1%</td><td colspan="2">Classroom D (northern classroom next to the atrium)- Average UDI (100- 3,000): 75.4%</td></tr>
<tr><td>UDI metrics</td><td>
</td><td>Average UDI-f: 31.9%
Average UDI-s: 32.4%
Average UDI-a: 35.7%
Average UDI-e: 0%</td><td>
</td><td>Average UDI-f: 22.1%
Average UDI-s: 35.3%
Average UDI-a: 52.1%
Average UDI-e: 0.5%</td></tr>
</table>

Table 0-13: False colour maps of UDI, UDI-e and UDI-f for each of the four classrooms in School E.

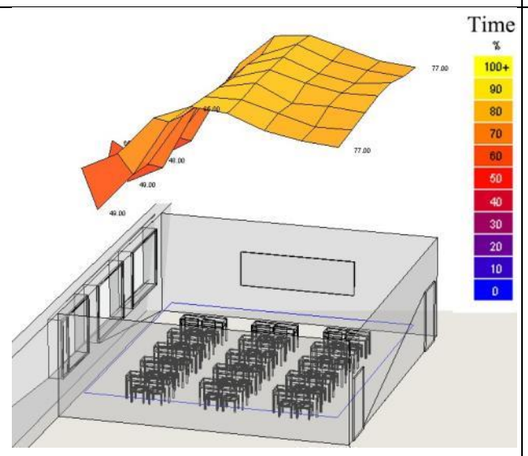
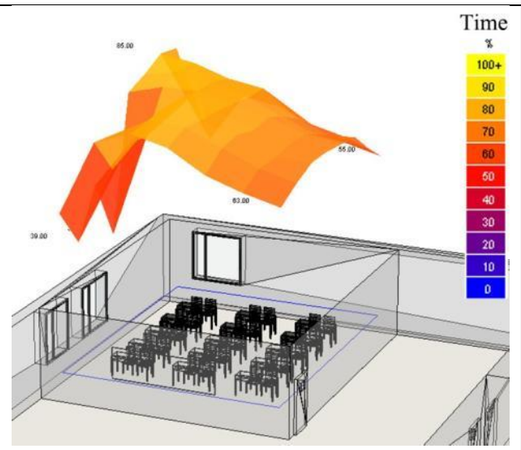
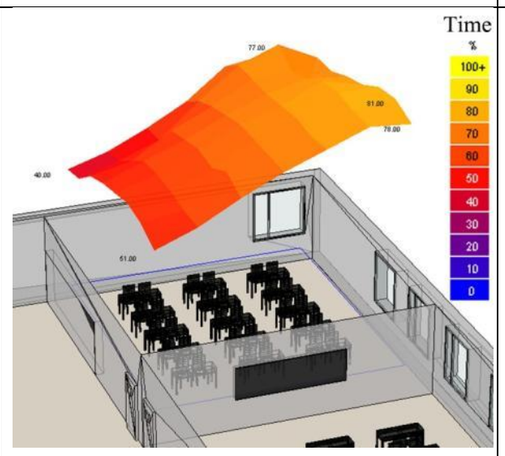
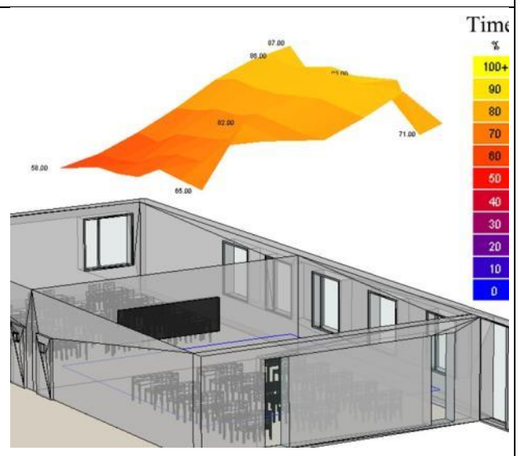
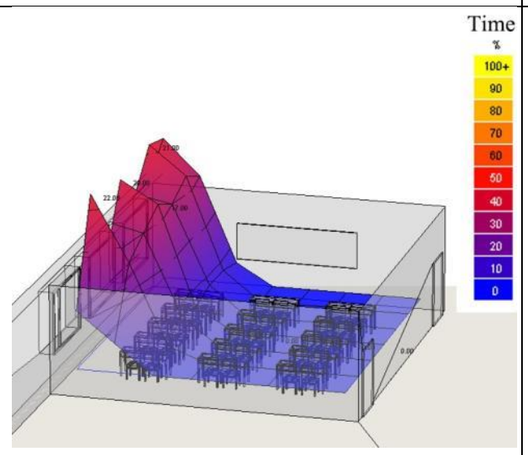
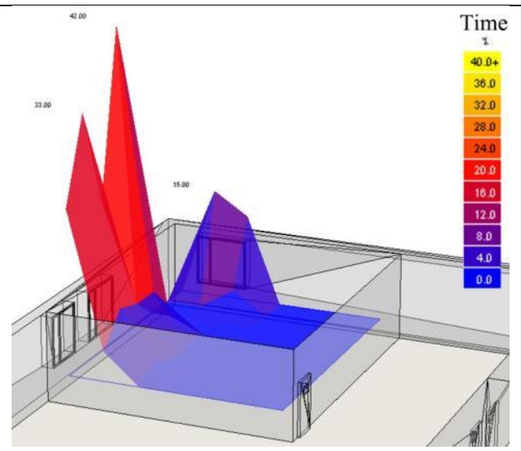
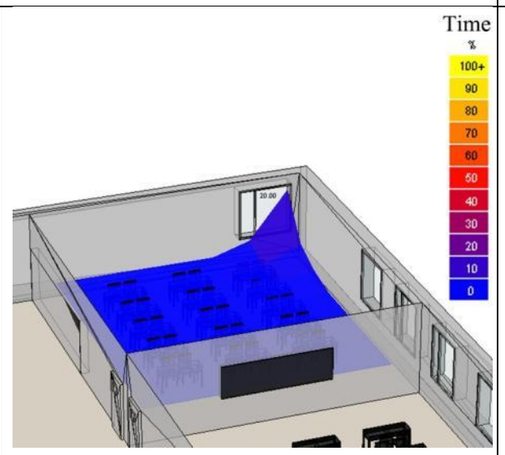
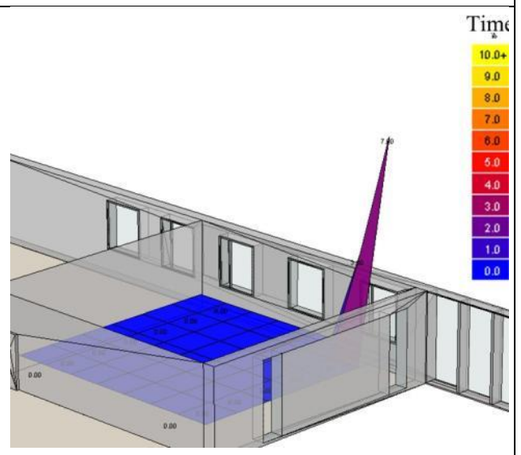
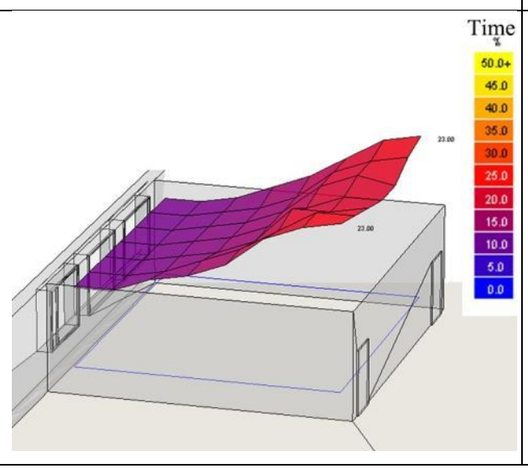
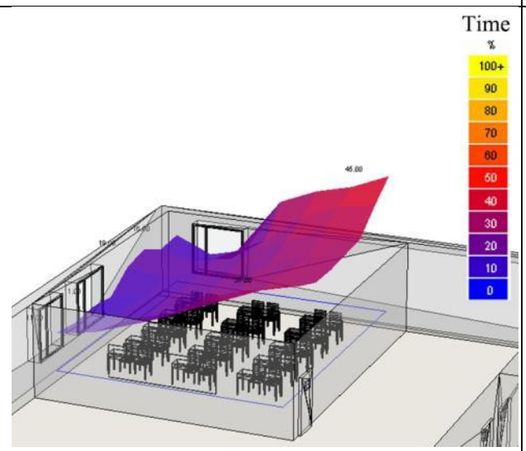
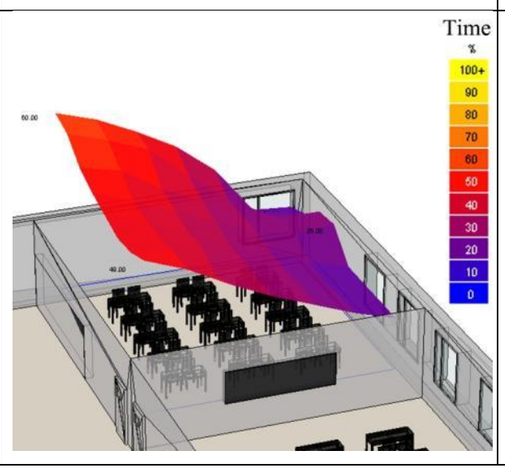
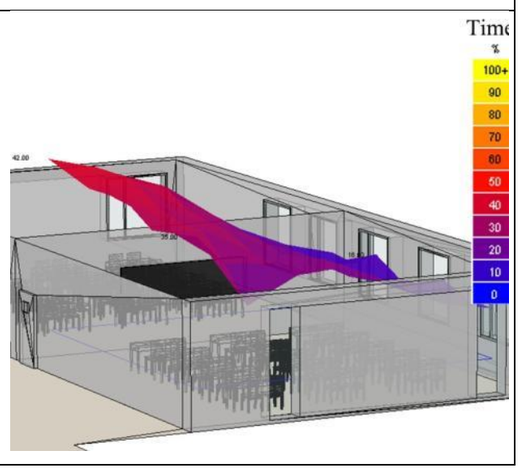
	Classroom A	Classroom B	Classroom C	Classroom D
UDI				
UDI -e				
UDI -f				

Table 0-14: Site shading analysis of School E (Source: Ecotect).

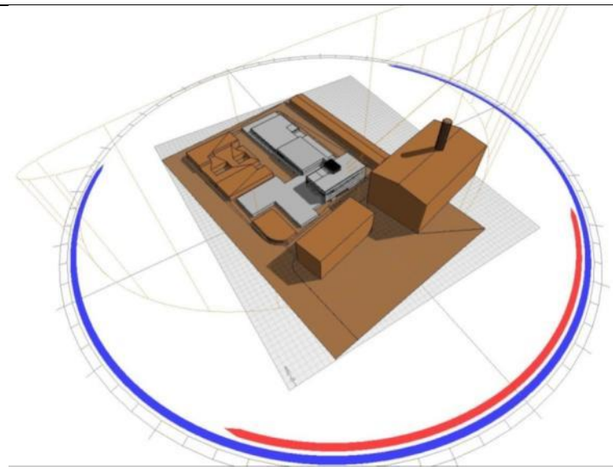
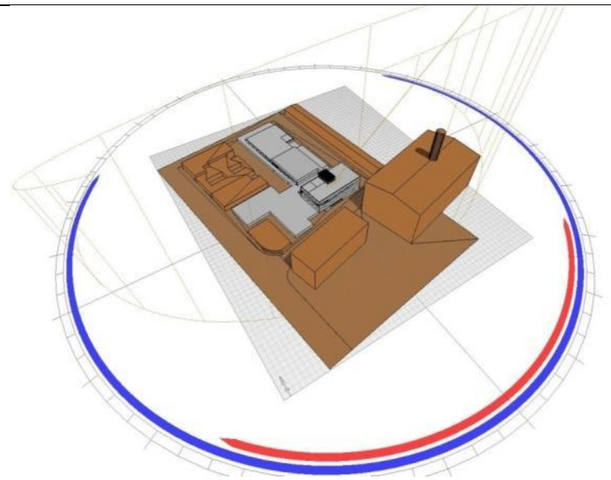
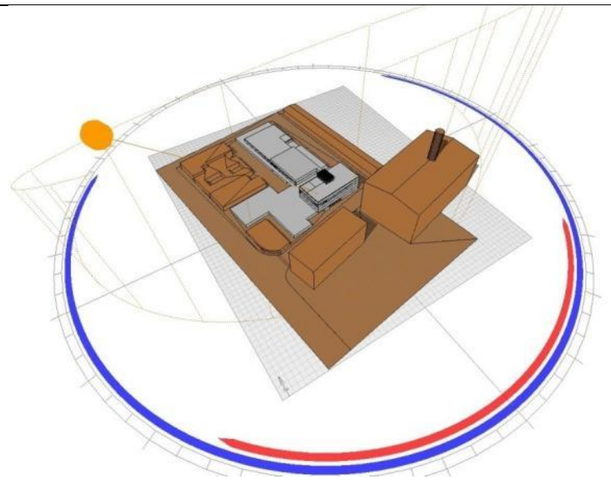
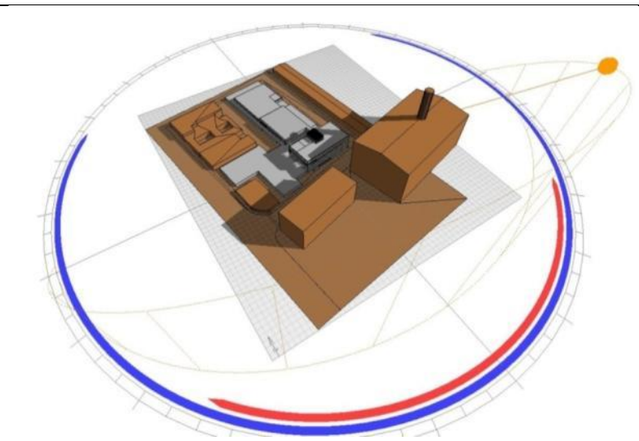
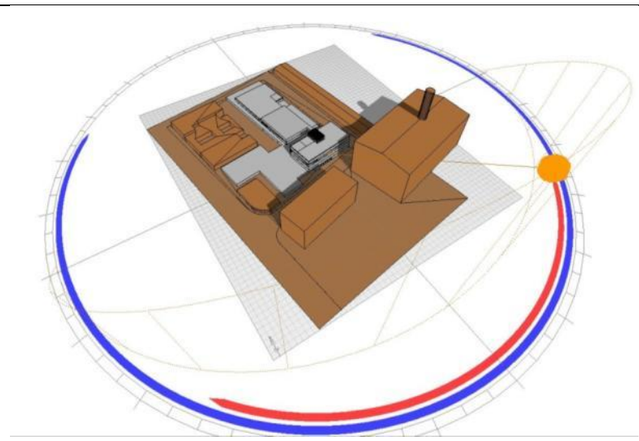
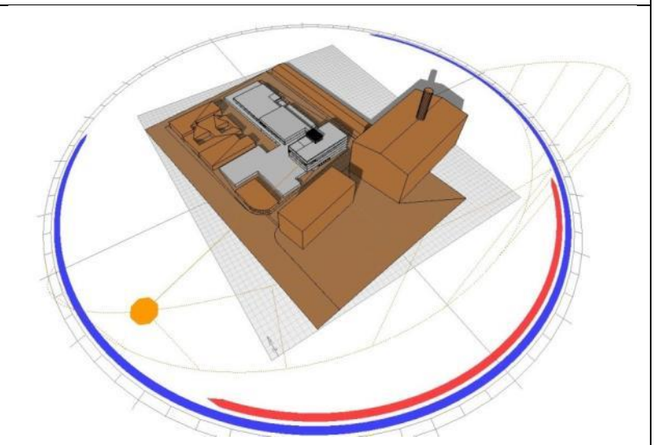
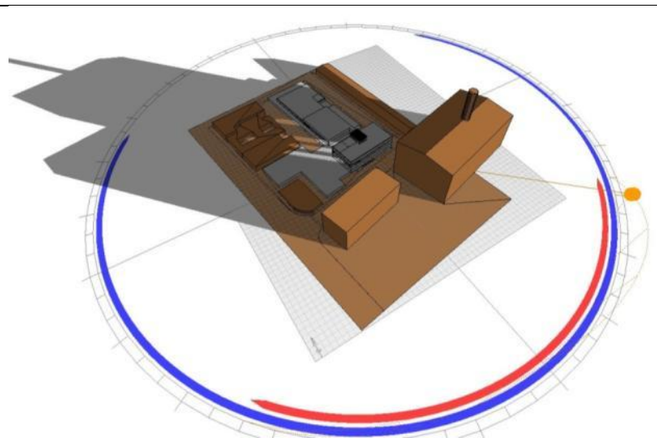
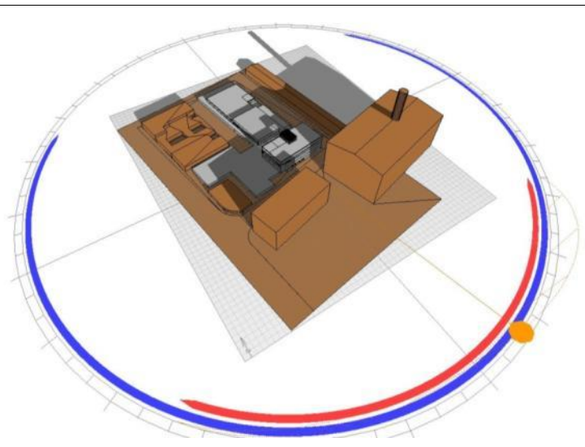
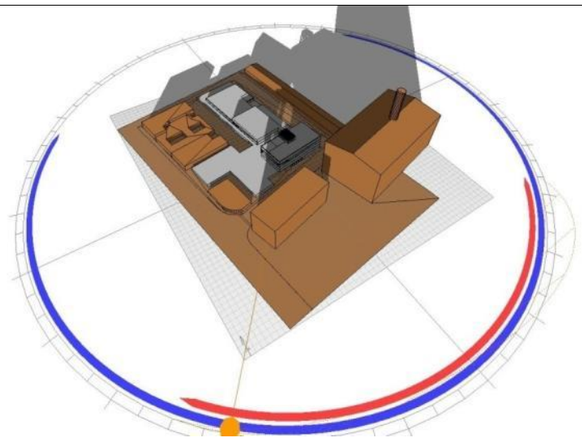
	9:00 a.m.	12:00 o'clock, noon	15:00 p.m.
Summer solstice			
Equinox			
Winter solstice			

Table 0-15: Fields of vision in classroom A (school E) on the summer solstice, the equinox, and the winter solstice at 9:00 a.m., 12:00 noon and 15:00 p.m. (Source: Radiance).

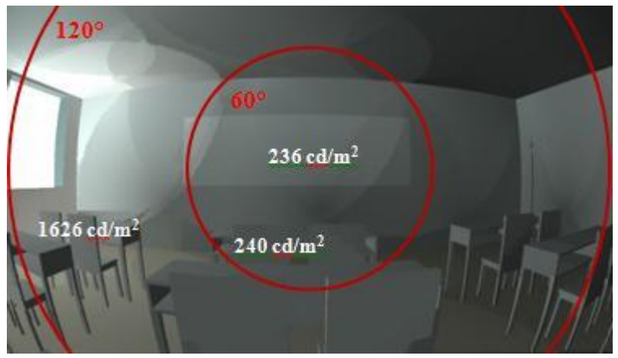
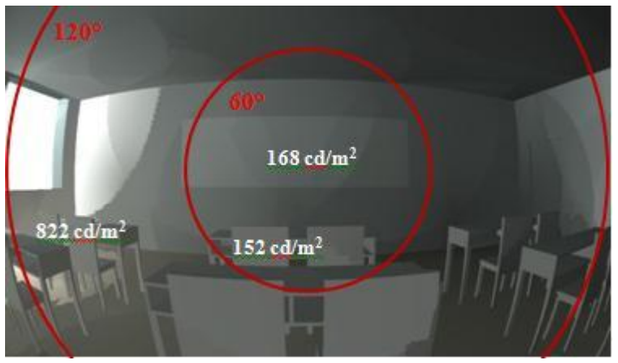
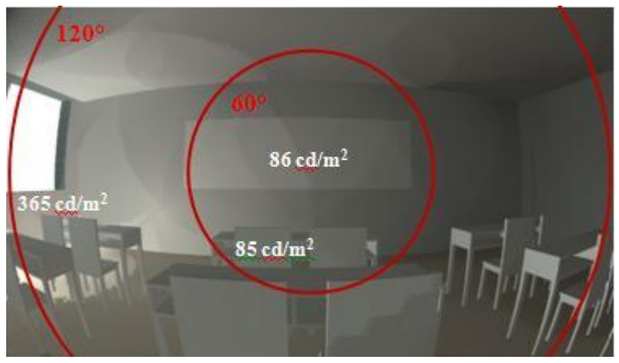
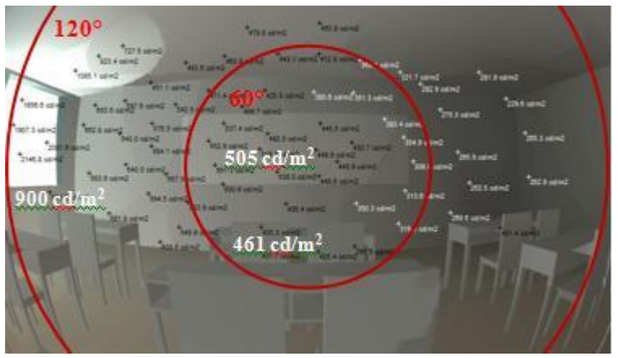
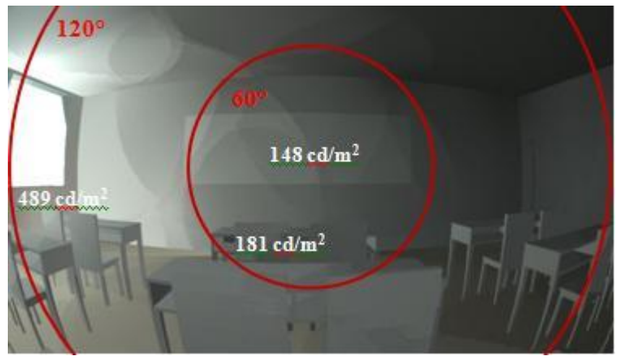
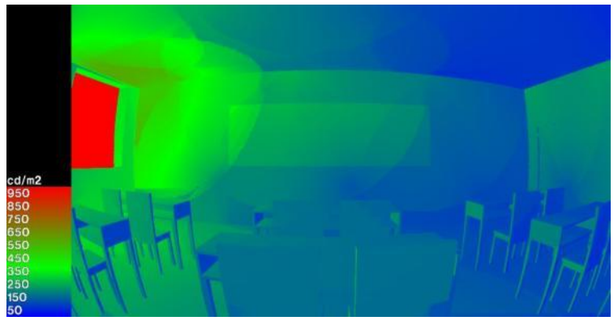
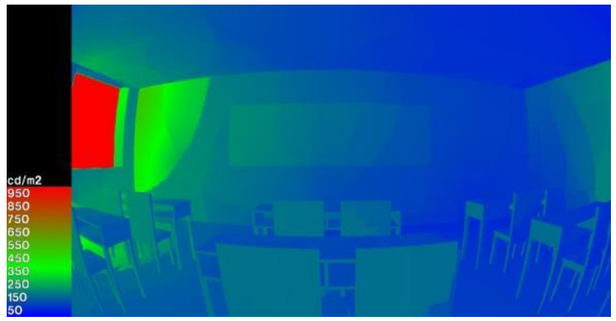
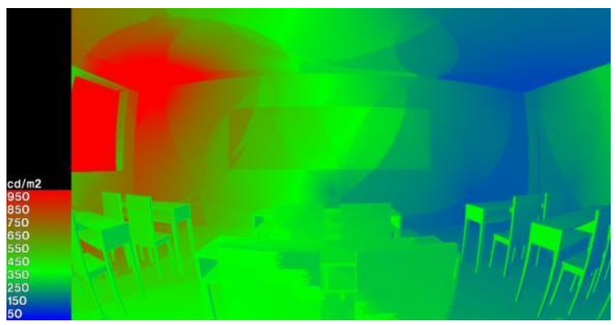
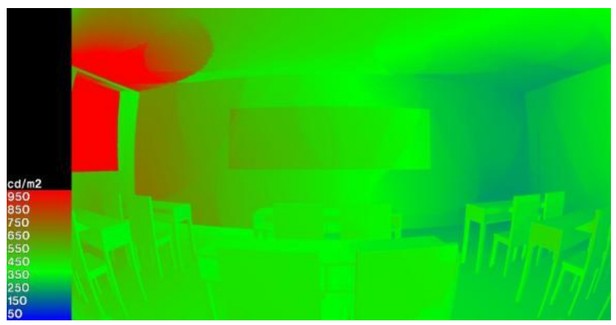
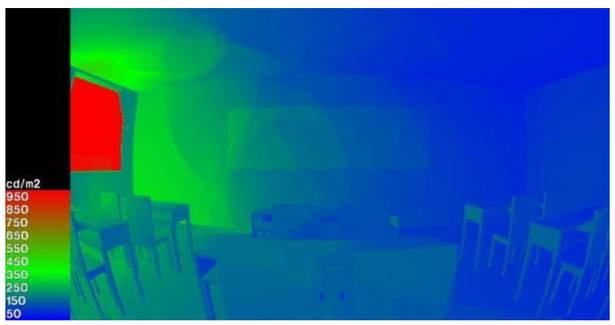
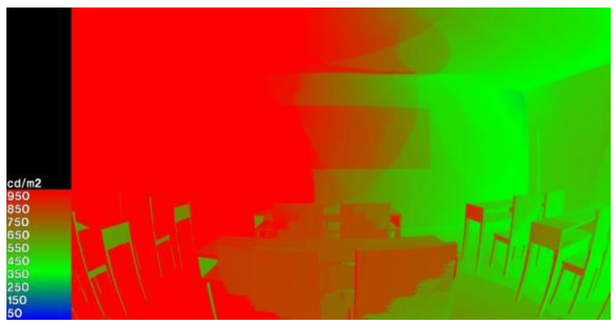
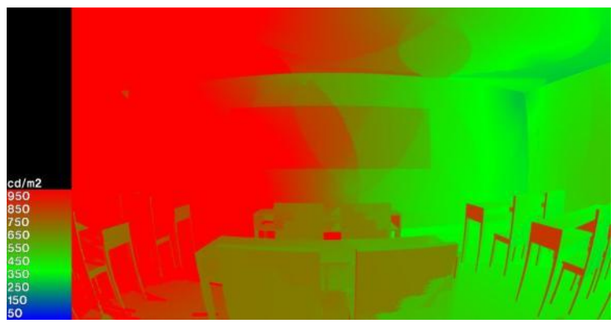
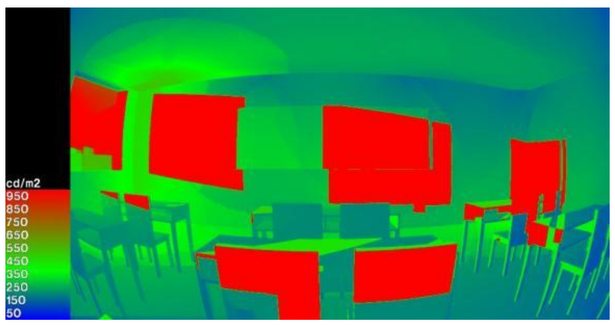
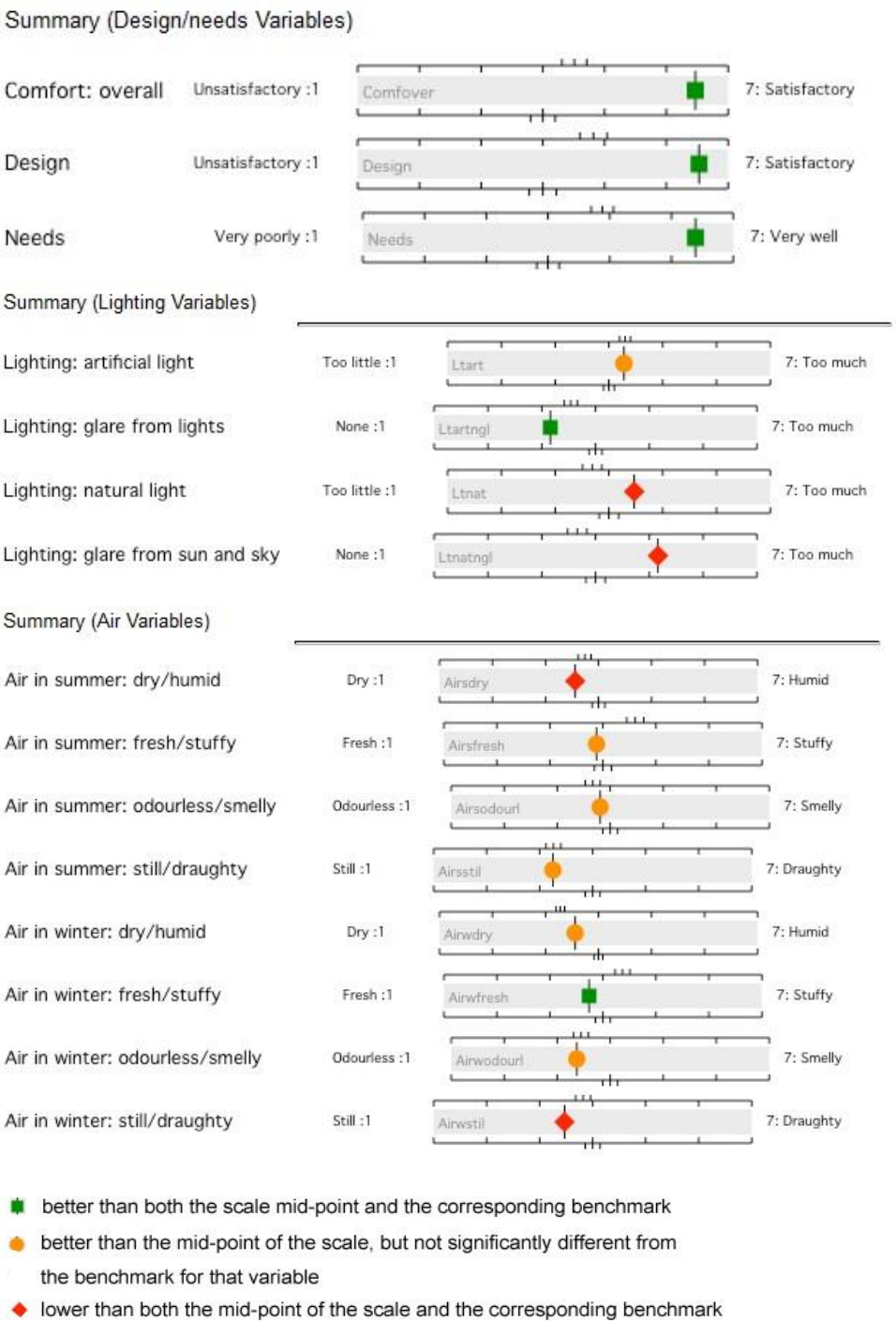
	Summer solstice	Equinox	Winter solstice
9:00 a.m.			
12:00 o'clock, noon			
15:00 p.m.			

Table 0-16: Corresponding false colour maps of internal luminance of classroom A in school E (Source: Radiance).

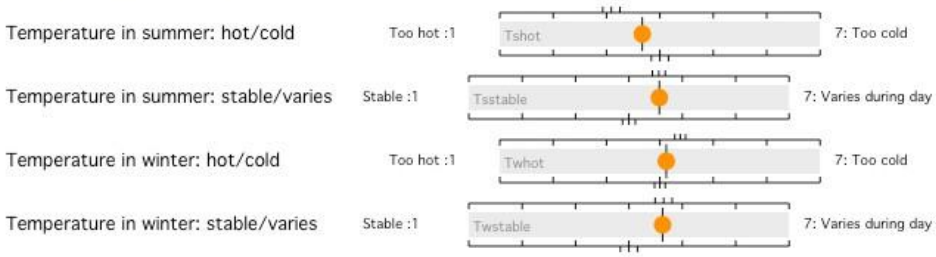
	Summer solstice	Equinox	Winter solstice
9:00 a.m.			
12:00 o'clock, noon			
15:00 p.m.			

Appendix 5: BUS occupant questionnaire results of the five schools studied

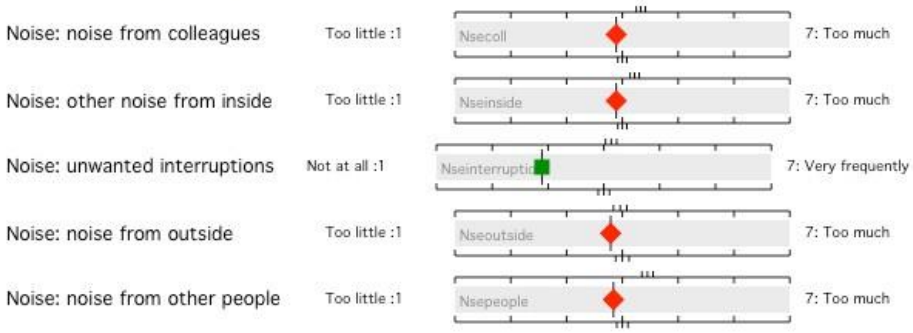
- School A



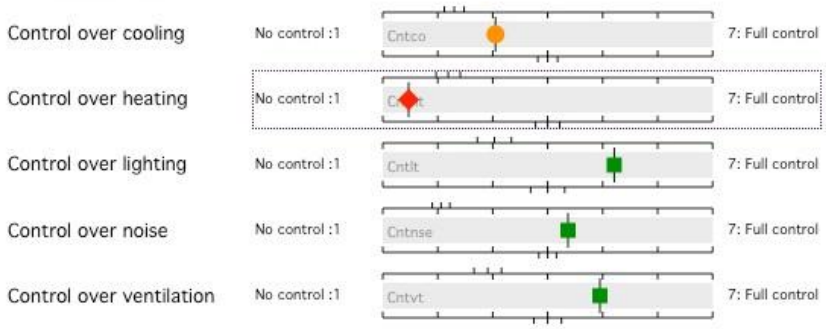
Summary (Temperature variables)



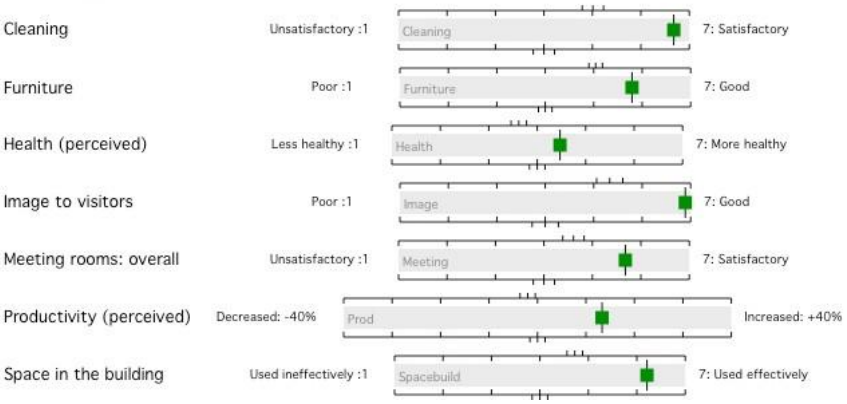
Summary (Noise Variables)



Summary (Control Variables)

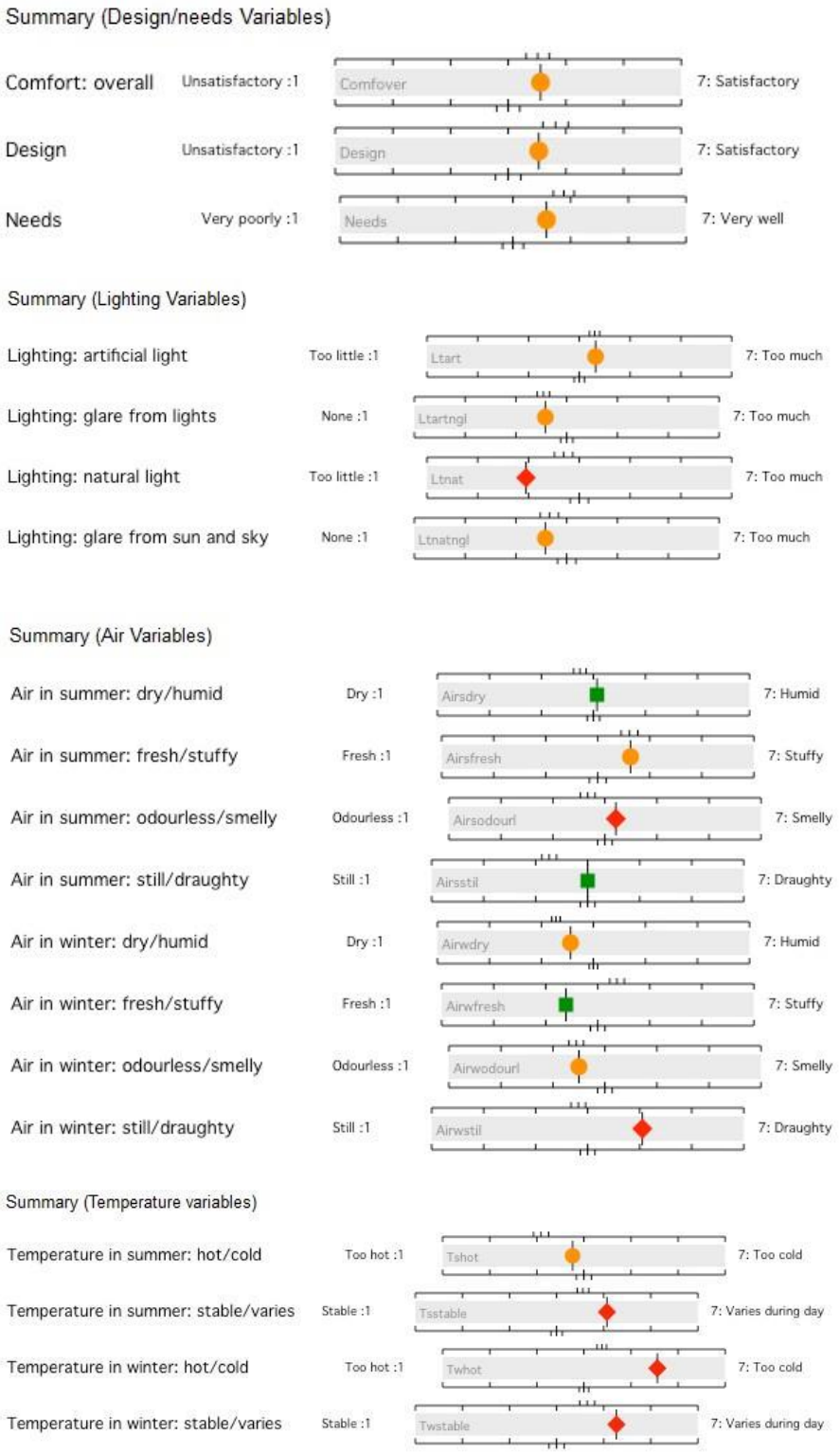


Summary (FM Variables)

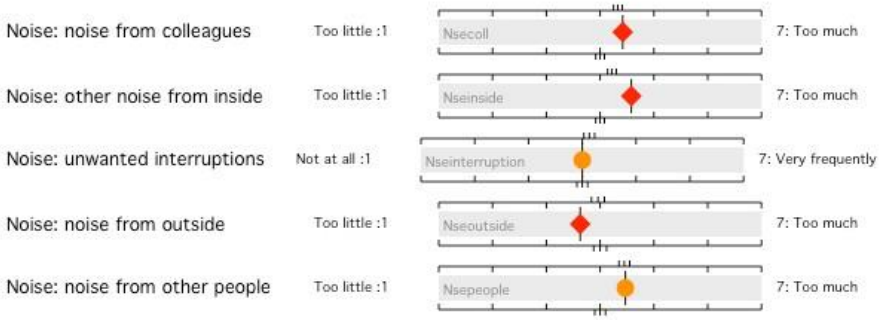


- better than both the scale mid-point and the corresponding benchmark
- better than the mid-point of the scale, but not significantly different from the benchmark for that variable
- lower than both the mid-point of the scale and the corresponding benchmark

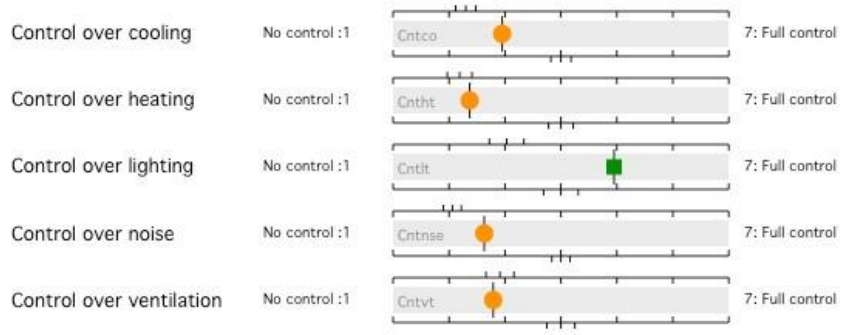
- School B


Summary (Design/needs Variables)
Comfort: overall
Unsatisfactory :1
Comfover
7: Satisfactory
Design
Unsatisfactory :1
Design
7: Satisfactory
Needs
Very poorly :1
Needs
7: Very well
Summary (Lighting Variables)
Lighting: artificial light
Too little :1
Ltart
7: Too much
Lighting: glare from lights
None :1
Ltartngl
7: Too much
Lighting: natural light
Too little :1
Ltnat
7: Too much
Lighting: glare from sun and sky
None :1
Ltnatngl
7: Too much
Summary (Air Variables)
Air in summer: dry/humid
Dry :1
Airsdry
7: Humid
Air in summer: fresh/stuffy
Fresh :1
Airsfresh
7: Stuffy
Air in summer: odourless/smelly
Odourless :1
Airsodourl
7: Smelly
Air in summer: still/draughty
Still :1
Airsstil
7: Draughty
Air in winter: dry/humid
Dry :1
Airwdry
7: Humid
Air in winter: fresh/stuffy
Fresh :1
Airwfresh
7: Stuffy
Air in winter: odourless/smelly
Odourless :1
Airwodourl
7: Smelly
Air in winter: still/draughty
Still :1
Airwstil
7: Draughty
Summary (Temperature variables)
Temperature in summer: hot/cold
Too hot :1
Tshot
7: Too cold
Temperature in summer: stable/varies
Stable :1
Tsstable
7: Varies during day
Temperature in winter: hot/cold
Too hot :1
Twhot
7: Too cold
Temperature in winter: stable/varies
Stable :1
Twstable
7: Varies during day
better than both the scale mid-point and the corresponding benchmark
better than the mid-point of the scale, but not significantly different from the benchmark for that variable
lower than both the mid-point of the scale and the corresponding benchmark

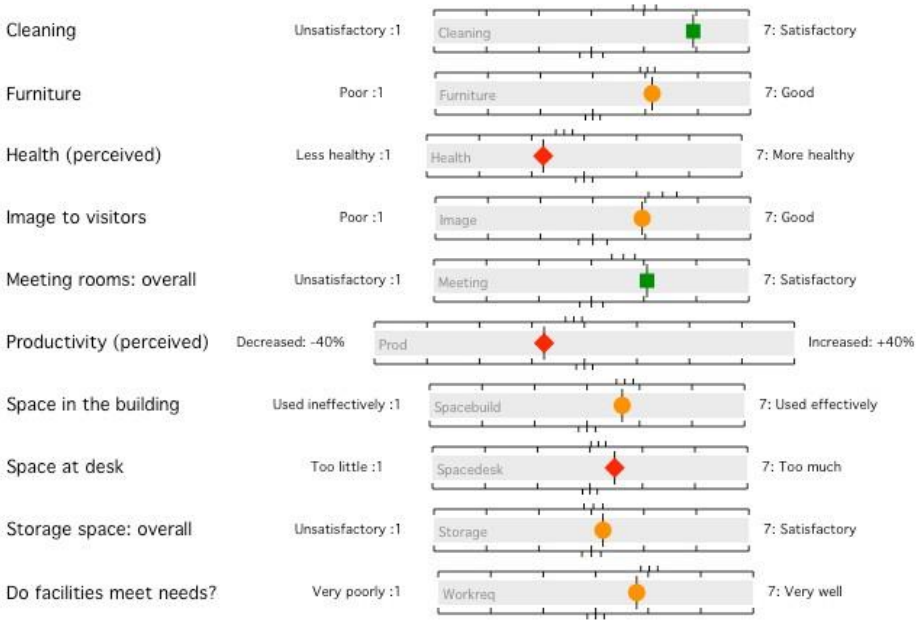
Summary (Noise Variables)



Summary (Control Variables)

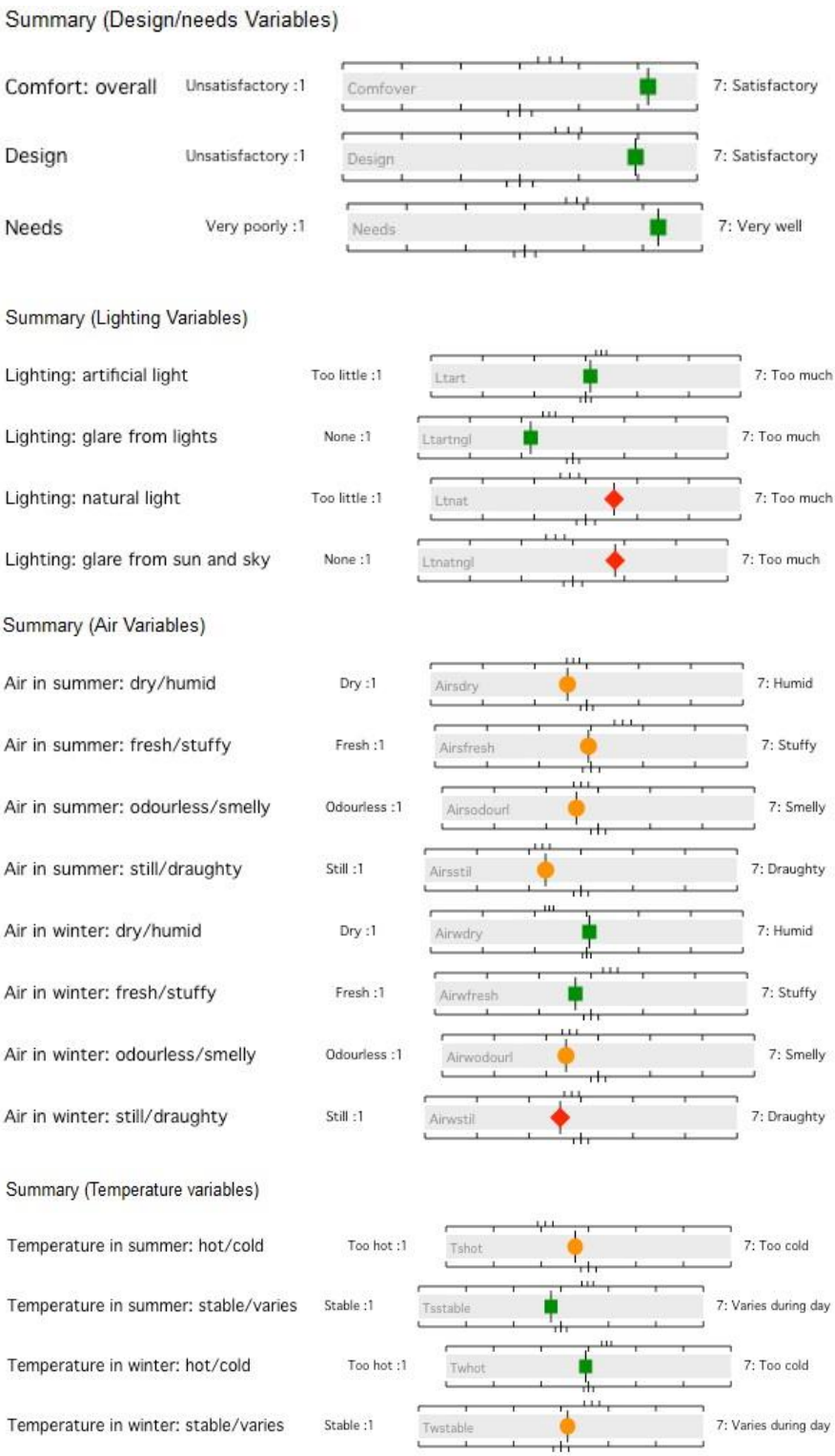


Summary (FM Variables)

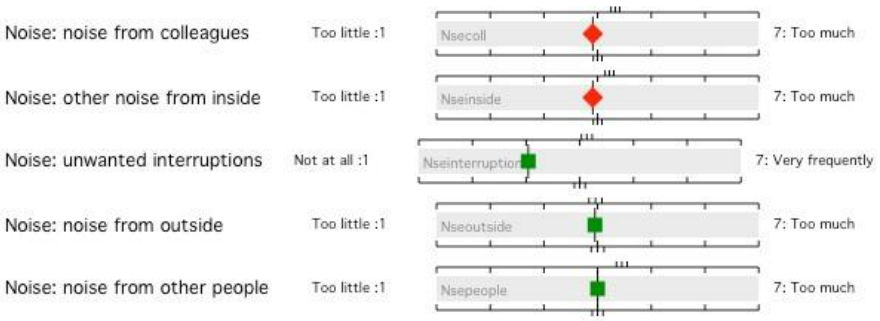


- better than both the scale mid-point and the corresponding benchmark
- better than the mid-point of the scale, but not significantly different from the benchmark for that variable
- lower than both the mid-point of the scale and the corresponding benchmark

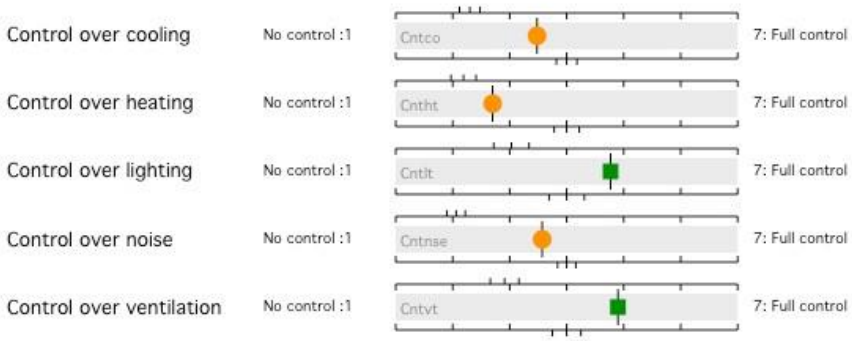
- School C


Summary (Design/needs Variables)
Comfort: overall
Unsatisfactory :1
Comfover
7: Satisfactory
Design
Unsatisfactory :1
Design
7: Satisfactory
Needs
Very poorly :1
Needs
7: Very well
Summary (Lighting Variables)
Lighting: artificial light
Too little :1
Ltart
7: Too much
Lighting: glare from lights
None :1
Ltartngl
7: Too much
Lighting: natural light
Too little :1
Ltnat
7: Too much
Lighting: glare from sun and sky
None :1
Ltnatngl
7: Too much
Summary (Air Variables)
Air in summer: dry/humid
Dry :1
Airsdry
7: Humid
Air in summer: fresh/stuffy
Fresh :1
Airsfresh
7: Stuffy
Air in summer: odourless/smelly
Odourless :1
Airsodourl
7: Smelly
Air in summer: still/draughty
Still :1
Airsstil
7: Draughty
Air in winter: dry/humid
Dry :1
Airwdry
7: Humid
Air in winter: fresh/stuffy
Fresh :1
Airwfresh
7: Stuffy
Air in winter: odourless/smelly
Odourless :1
Airwodourl
7: Smelly
Air in winter: still/draughty
Still :1
Airwstil
7: Draughty
Summary (Temperature variables)
Temperature in summer: hot/cold
Too hot :1
Tshot
7: Too cold
Temperature in summer: stable/varies
Stable :1
Tsstable
7: Varies during day
Temperature in winter: hot/cold
Too hot :1
Twhot
7: Too cold
Temperature in winter: stable/varies
Stable :1
Twstable
7: Varies during day
better than both the scale mid-point and the corresponding benchmark
better than the mid-point of the scale, but not significantly different from the benchmark for that variable
lower than both the mid-point of the scale and the corresponding benchmark

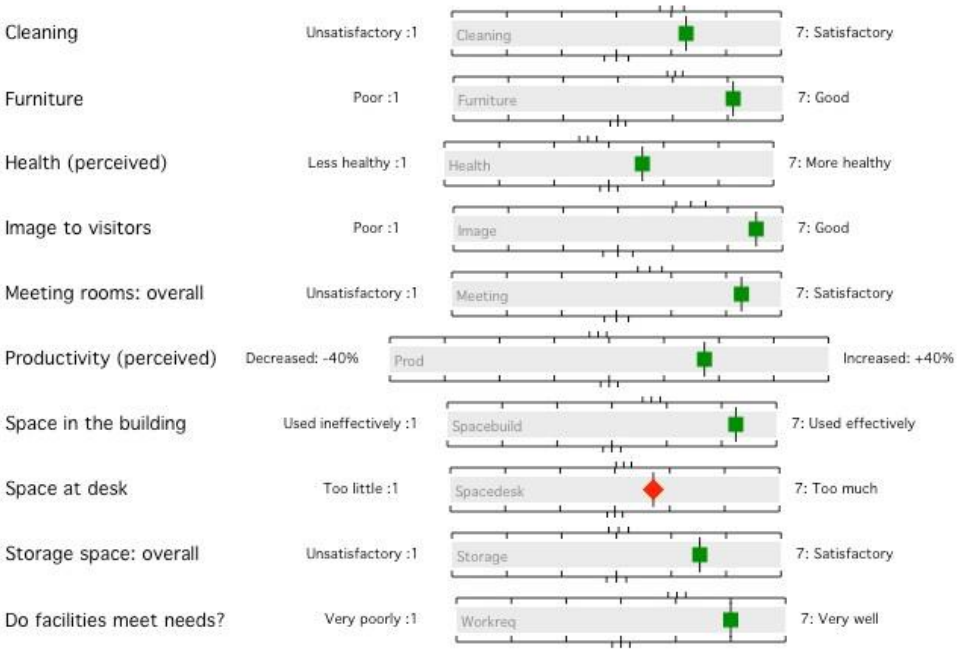
Summary (Noise Variables)



Summary (Control Variables)

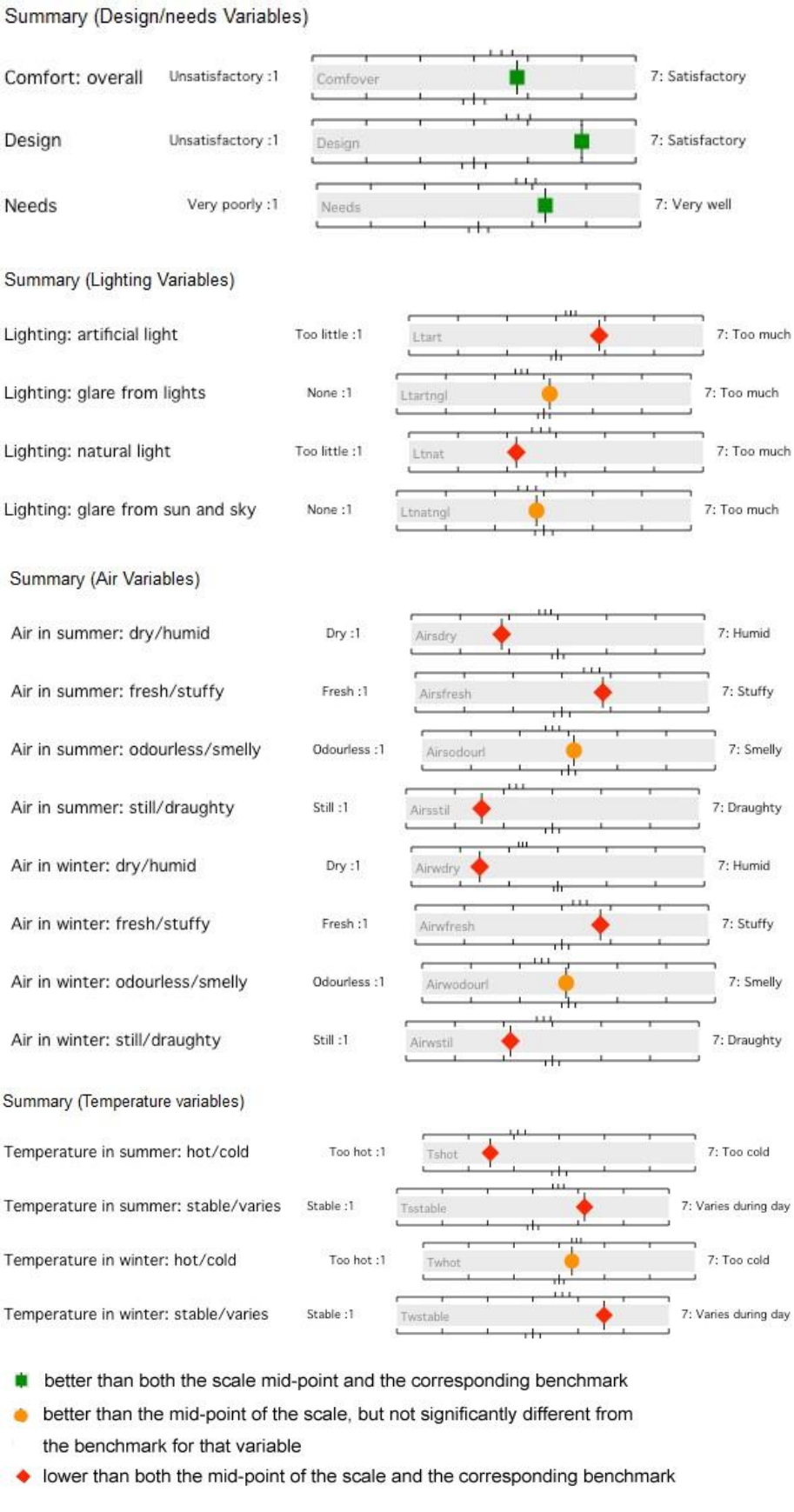


Summary (FM Variables)

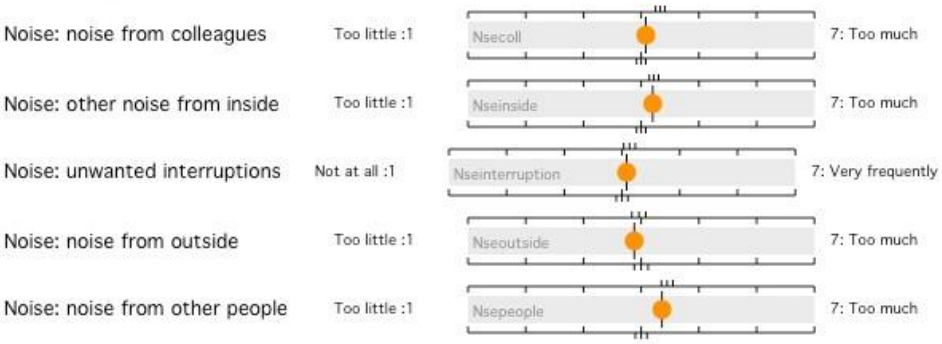


- better than both the scale mid-point and the corresponding benchmark
- better than the mid-point of the scale, but not significantly different from the benchmark for that variable
- lower than both the mid-point of the scale and the corresponding benchmark

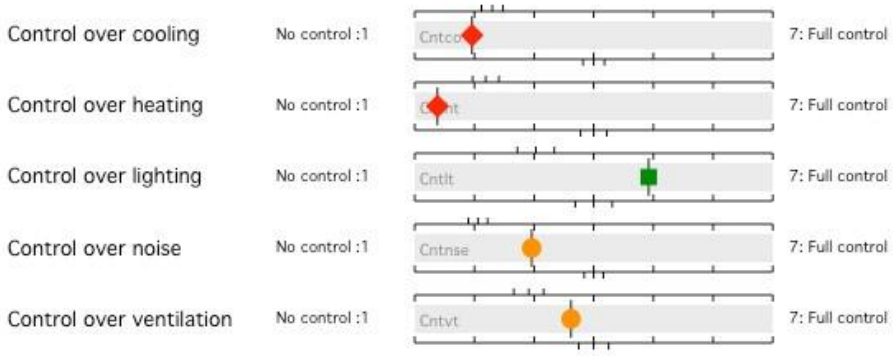
- School D


Summary (Design/needs Variables)
Comfort: overall
Unsatisfactory :1
Comfover
7: Satisfactory
Design
Unsatisfactory :1
Design
7: Satisfactory
Needs
Very poorly :1
Needs
7: Very well
Summary (Lighting Variables)
Lighting: artificial light
Too little :1
Ltart
7: Too much
Lighting: glare from lights
None :1
Ltartngl
7: Too much
Lighting: natural light
Too little :1
Ltnat
7: Too much
Lighting: glare from sun and sky
None :1
Ltnatngl
7: Too much
Summary (Air Variables)
Air in summer: dry/humid
Dry :1
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Fresh :1
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Air in summer: odourless/smelly
Odourless :1
Airsodourl
7: Smelly
Air in summer: still/draughty
Still :1
Airsstil
7: Draughty
Air in winter: dry/humid
Dry :1
Airwdry
7: Humid
Air in winter: fresh/stuffy
Fresh :1
Airwfresh
7: Stuffy
Air in winter: odourless/smelly
Odourless :1
Airwodourl
7: Smelly
Air in winter: still/draughty
Still :1
Airwstil
7: Draughty
Summary (Temperature variables)
Temperature in summer: hot/cold
Too hot :1
Tshot
7: Too cold
Temperature in summer: stable/varies
Stable :1
Tsstable
7: Varies during day
Temperature in winter: hot/cold
Too hot :1
Twhot
7: Too cold
Temperature in winter: stable/varies
Stable :1
Twstable
7: Varies during day
better than both the scale mid-point and the corresponding benchmark
better than the mid-point of the scale, but not significantly different from the benchmark for that variable
lower than both the mid-point of the scale and the corresponding benchmark

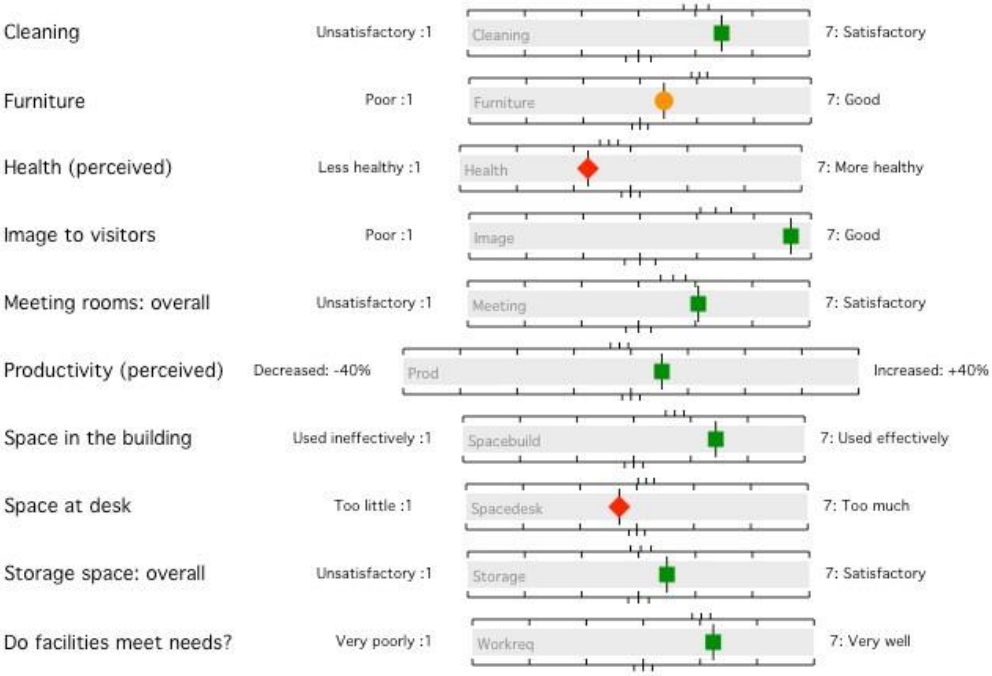
Summary (Noise Variables)



Summary (Control Variables)

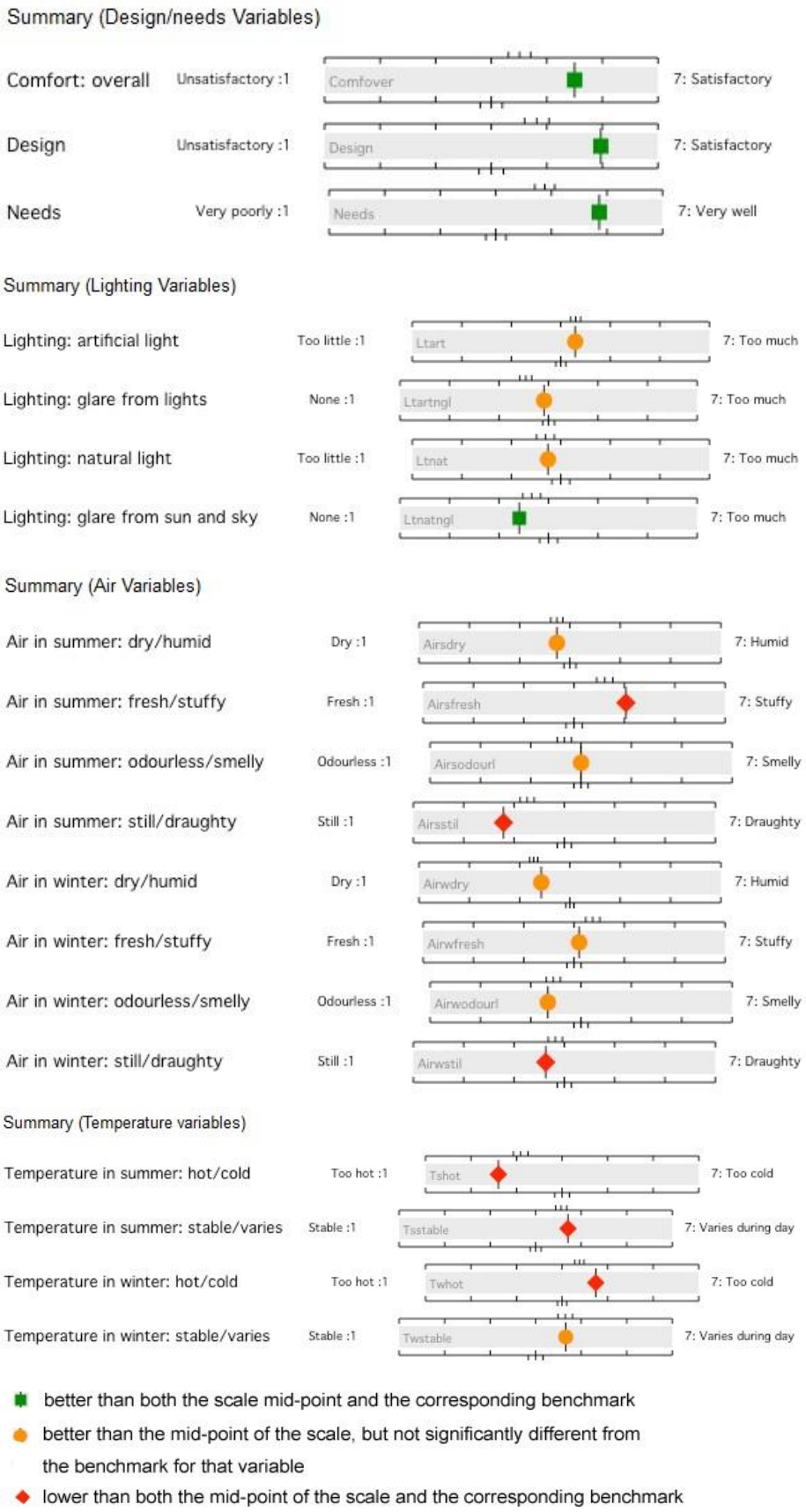


Summary (FM Variables)

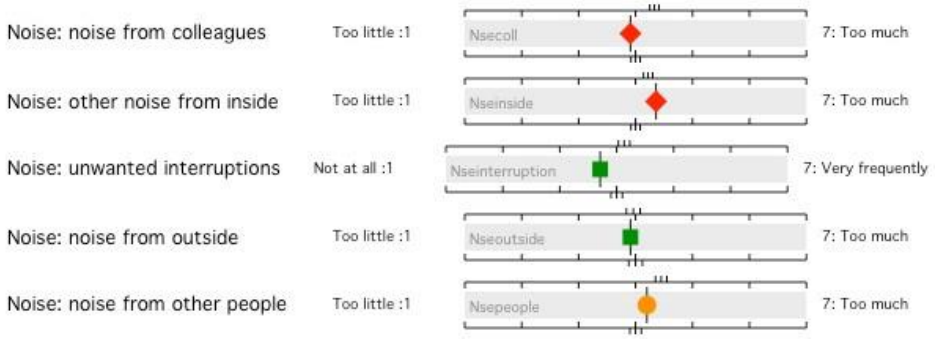


- better than both the scale mid-point and the corresponding benchmark
- better than the mid-point of the scale, but not significantly different from the benchmark for that variable
- lower than both the mid-point of the scale and the corresponding benchmark

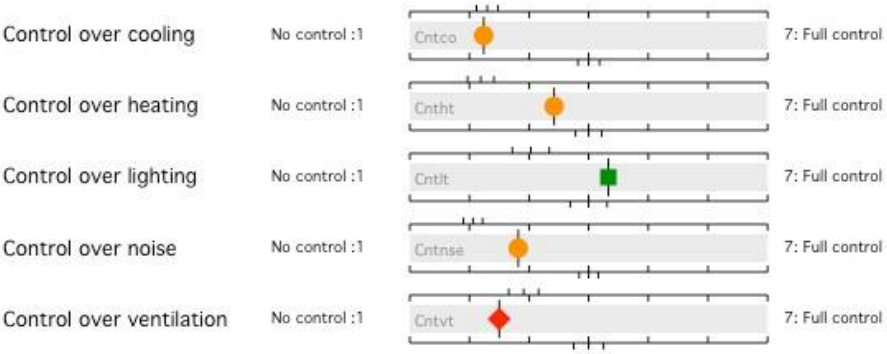
- School E


Summary (Design/needs Variables)
Comfort: overall
Unsatisfactory :1
Comfover
7: Satisfactory
Design
Unsatisfactory :1
Design
7: Satisfactory
Needs
Very poorly :1
Needs
7: Very well
Summary (Lighting Variables)
Lighting: artificial light
Too little :1
Ltart
7: Too much
Lighting: glare from lights
None :1
Ltartngl
7: Too much
Lighting: natural light
Too little :1
Ltnat
7: Too much
Lighting: glare from sun and sky
None :1
Ltnatngl
7: Too much
Summary (Air Variables)
Air in summer: dry/humid
Dry :1
Airsdry
7: Humid
Air in summer: fresh/stuffy
Fresh :1
Airsfresh
7: Stuffy
Air in summer: odourless/smelly
Odourless :1
Airsodourl
7: Smelly
Air in summer: still/draughty
Still :1
Airsstil
7: Draughty
Air in winter: dry/humid
Dry :1
Airwdry
7: Humid
Air in winter: fresh/stuffy
Fresh :1
Airwfresh
7: Stuffy
Air in winter: odourless/smelly
Odourless :1
Airwodourl
7: Smelly
Air in winter: still/draughty
Still :1
Airwstil
7: Draughty
Summary (Temperature variables)
Temperature in summer: hot/cold
Too hot :1
Tshot
7: Too cold
Temperature in summer: stable/varies
Stable :1
Tsstable
7: Varies during day
Temperature in winter: hot/cold
Too hot :1
Twhot
7: Too cold
Temperature in winter: stable/varies
Stable :1
Twstable
7: Varies during day
better than both the scale mid-point and the corresponding benchmark
better than the mid-point of the scale, but not significantly different from the benchmark for that variable
lower than both the mid-point of the scale and the corresponding benchmark

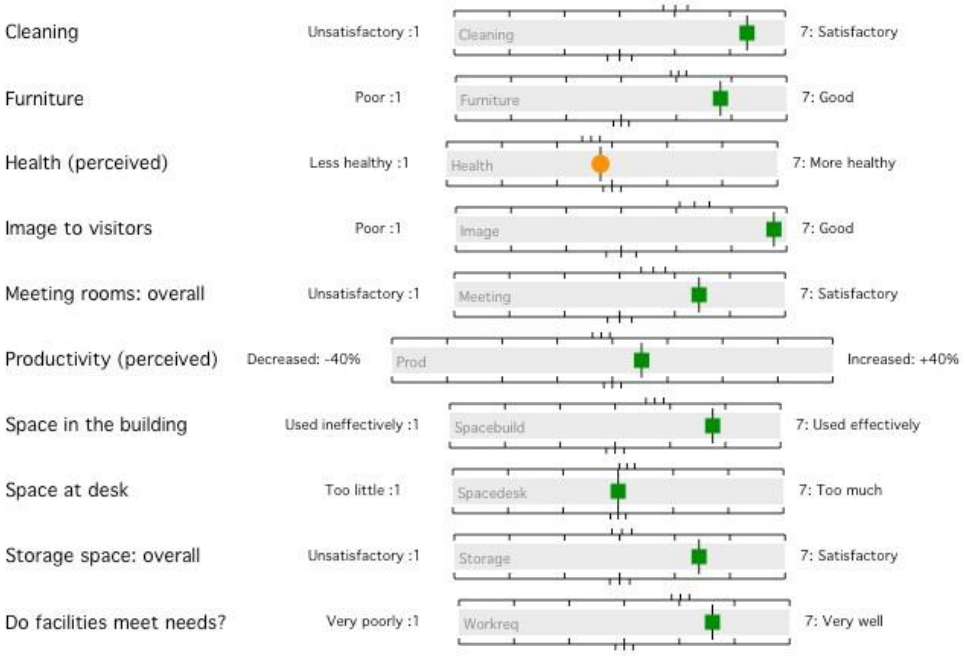
Summary (Noise Variables)



Summary (Control Variables)



Summary (FM Variables)



- better than both the scale mid-point and the corresponding benchmark
- better than the mid-point of the scale, but not significantly different from the benchmark for that variable
- lower than both the mid-point of the scale and the corresponding benchmark

Appendix 6: RIBA Awards documentation

RIBA

RIBA Awards 2014

The deadline for all UK and EU entries excluding Scotland is midnight on Friday 7 February. For entrants with buildings based in Scotland please visit www.rias.org to enter the awards.

Awards and eligibility - **Before applying online please read all the information on this page**

RIBA Regional, National, EU Awards and RIBA Stirling Prize are for buildings in the UK or EU by RIBA Chartered Architects and RIBA International Fellows.

A Regional Award: is for the important contribution to (the discipline of) Architecture

An RIBA National Award: is for a significant contribution to (the discipline of) Architecture

An RIBA EU Award: is for a significant contribution to (the discipline of) Architecture outside the UK but within the EU

The RIBA Stirling Prize: is for the exceptional contribution to (the discipline of) Architecture

The RIBA's International Awards are changing with the development of a new International Prize, a successor to the RIBA Lubetkin Prize. Practices will be invited to enter projects for the new international award, in summer 2015. **There will be no International Awards or Lubetkin Prize in 2014.**

The Regional awards and Regional special prizes (excl Scotland and Northern Ireland) are judged and presented locally. Entrants who win a Regional award can then be considered for an RIBA National award, the winners of these are then eligible for the prestigious RIBA Stirling Prize which will be presented in October 2014.

To be eligible to apply the four points below must be met

- Ensure you are a current RIBA Chartered member or RIBA International Fellow
- Your building(s) must be completed and occupied (partially occupied commercial and housing projects subject to RIBA approval) between 1 January 2012 and February 2014.
- Clients' permission to submit the building has been obtained prior to application.
- If the practice submitting the building worked in collaboration with another practice, both architects must be in agreement on the entry and how the building should be credited.

As an entrant you could win -

RIBA Chartered architect or RIBA International Fellow, building in the UK:

- Regional Award
- Regional Special Award (if building meets the specific criteria)
- RIBA National Award
- RIBA National Special Award (if building meeting the specific criteria)
- RIBA Stirling Prize

RIBA Chartered architect building outside of the UK but in the EU:

- RIBA EU Award
- RIBA Stirling Prize

RIBA International Fellow building outside of the UK but in the EU:

- RIBA EU Award

How to enter - creating your application

Create your personal login for your awards entry with an RIBA Chartered membership number and your email address. The membership number should be 8 digits long and contain numbers only e.g. 12345678

If you are an International Fellow you must contact clemency.christopherson@riba.org for your membership number

Once you have started your online entry you may work on your submission(s) right up until the closing date

To complete your online entry you will need to provide the following

1. **EU entries only** (projects outside of the UK but within the EU) – a hard copy A1 board, preferably landscape, this should include: the name and location of the project, name of the practice and any additional practice to be credited, up to six - eight images (internal and external), a plan and section, up to 300 words describing the project. **This must be mailed to RIBA Awards Office, RIBA, 66 Portland Place, W1B 1AD, UK**. We strongly recommend that postage is made as special delivery or recorded as the RIBA will not be responsible for undelivered items. The RIBA will not pay for any customs or VAT fees incurred in the posting of entries. A1 boards will not be posted back to the entrant.

2. **All entries -** Project name, project address with postcode, practice address, name of any other practices to be credited (if applicable), gross internal area in sq m, in the case of largely landscape/urban design projects gross external area in sq m, cost of

project incl build and fit out if done/overseen by the architect (excl land costs and fees), cost per sq m and occupation date of the project.

3. **All entries** - Contact details for project director/architect, client, contact for jury visits (if different from project director/architect and client), marketing/pr contact if external to the practice entering and contractor of the project.

4. **All entries** - Entrant must choose the RIBA Region for the project, this is based on where the project is located not the practice entering.

5. **All entries** - 300-500 words describing the project setting out client's brief, planning constraints, materials and method of construction, summary of time-table, programme and budget constraints, and a short statement on how the project meets the principles of inclusive design.

6. **UK entries only** – if your project is eligible and you wish to be considered for them, up to 300 words in support of each application for Regional Special Awards (apart from Regional Sustainability prize – see 12), these are:

- Regional Conservation award - the project should respect and enhance the original buildings but also have regard to the wider context. Projects may also demonstrate an understanding of and give reference to the vernacular traditions and materials of their locality.
- Regional Small projects award – for projects under £250,000. The project should demonstrate creativity and architectural merit within the limits of its budget.
- Regional Sustainability award – for projects which go beyond statutory requirements and demonstrate elegantly and durably the principles of sustainable architecture. (Judges will use sustainability statement supplied for all awards – see 12)
- Regional Client of the Year award - rewards the Client's demonstrable commitment to procuring and achieving quality architecture.
- Regional Architect of the Year - this new award is given to an established architect or practice based in the region, on the basis of a regional award made in the same year but also taking into account a track record of previous award-winning schemes.
- Regional Emerging Architect of the Year - this new award is given to an 'emerging' architect or practice based in the region, on the basis of a regional award made in the same year. This might mean either an architect or practice winning its first RIBA Award, OR one established within the past five years, OR an individual architect under 45.
- Regional Building of the Year - the project which best demonstrates architectural excellence whilst contributing positively to its economic, social, environmental and cultural context. It has made a significant contribution to the discipline of architecture in this Region in 2014 and is therefore recommended for a National RIBA Prize.

7. **UK entries only** – if your project is eligible and you wish to be considered for them, up to 300 words in support of each application for National Special Awards, these are:

- RIBA Manser Medal - to encourage innovation in house design, to show how social and technological ambitions can be met by intelligent design and to produce exemplars to be taken up by the wider house building industry. The prize is named after Michael Manser, former President of the RIBA, who is well known for his own steel and glass house designs.
- Stephen Lawrence Prize – The RIBA Stephen Lawrence Prize is funded by the Marco Goldschmied Foundation, and was set up in memory of the teenager who was setting out on the road to becoming an architect when he was murdered in 1993. The prize, which rewards the best examples of projects that have a construction budget of less than £1 million, is intended to encourage fresh talent working with smaller budgets.
- RIBA Client of the Year award - honours the key role that a good client plays in the creation of fine architecture.

8. **All entries** - A list of key consultants to be credited (structural engineer, services engineer, landscape architects etc) with contact details.

9. **All entries** – name and contact details of photographer/s. The architect must have the agreement of the photographer that these images may be used free of copyright for the purpose only of promoting the awards.

10. **All entries** - A one-page pdf to be uploaded by the entrant which summarises the project. Designed to be an at-a glance summary of the project, this should include: the name and location of the project, up to four images (internal and external), a plan and section, up to 100 words describing the project. This should include the name of the practice and any additional practice to be credited.

11. **All entries** - A sustainability statement, provided by the RIBA for entrants to be uploaded by the entrant. In this two page word document the entrant should provide annual energy figures (if project has not been occupied for a year please provide projected figures) describe the building's performance in use, with particular reference to energy use for all entries, and energy performance figures and statistics signed off by an environmental engineer for all projects with a contract value of over £1m. No such scheme will be considered for an award without the required information.

12. **All entries** - Entrants **must** upload 8-12 images as jpegs; they should be a mixture of external and internal shots of the project. These images are used for judging purposes, they should convey and highlight what is good about the project, we advise both wide shots and closes ups and if possible show the building in use.

- Entrants **must** also upload up to 8 plans as jpegs or pdf which **must** include a location plan, site plan, floor plans, elevations and sections).

- Each image and plan **must** be uploaded as separate files, if they are not you will be asked to resubmit them. Please refer to below for format and naming convention.
- **Images,** file type: JPEG, Quality and size: up to 5mb in size, no less than 2mb, DPI: 300, Please note no symbols in the naming protocol: ProjectName01PhotographerName.jpg.
- Plans, file type: JPEG or PDF, Quality and size: up to 3mb in size, no less than 500kb, please note no symbols in the naming protocol: ProjectName01Plantype.

13. **All entries** - Online entry payment by credit card or debit card

Each entry requires one payment. The entry fee is dependent on the value of the building entered, see payment bands below **(applicable to all entrants, including EU).**

- Payments must be made separately, i.e. they cannot be grouped together for multiple entries and you must pay the full amount, including VAT.
- Payments must be made online using a valid credit or debit card at the end of the entry process.
- Once payment is made you **cannot alter** your entry - payment results in the final submission of your entry.

Entry costs: These are unchanged from 2013

- Building value up to £350k - £75 + VAT £15 = £90
- Building value between £350k & £1m - £160 +VAT £32 = £192
- Building value between £1m & £5m - £295 & VAT £59 = £354
- Building value between £5m & £20m - £420 + VAT £84 = £504
- Building value over £20m - £450 + VAT £90 = £540

Judging and criteria – how it's done and what the judges are looking for

RIBA Awards judging 2014

All RIBA Awards are judged by RIBA Members and lay assessors. Every judge plays a crucial part in a rigorous and thorough process that leads ultimately to the RIBA Stirling Prize.

Judging involves balancing the complexities that any building project will have faced with aesthetic, sustainability and perhaps conservation considerations, as well as the local context. It requires an examination of the client's brief and how intelligently and creatively that has been fulfilled, whilst taking into account the constraints of budget and planning. It means taking a collective view and having a clear vision on what constitutes architectural excellence.

What does a Regional Jury do?

The Regional juries, consisting of a Regional Jury Chair, Regional Representative, Regional Lay Assessor, Sustainability Specialist and Conservation specialist, plus two architects drawn from across the region will meet in Feb/March 2014 in the relevant region. Using the entry materials provided, they will discuss and decide which projects will be shortlisted and visited.

The RIBA regional offices organise all jury visits and will contact the architect directly, inviting both architect and client to the visit. Regional jury visits should take place in March/April 2014. Once visits have been completed the jury will decide their Regional winners, Regional special awards and their recommendations for their RIBA National Award shortlists. Regional Awards will be announced at awards events across the country in the months of April and May.

What does a National Jury do?

The National juries, consisting of a National Jury Chair and Regional Representative (the person who chaired the regional jury) will meet in April/May 2014. Using entry materials provided and recommendations from the Regional juries they will discuss and decide which projects will be shortlisted and visited.

The RIBA regional offices organise all jury visits and will contact the architect directly, inviting both architect and client to the visit. National Jury visits will take place in May 2014. Once visits have been completed the National Jury Chairs will meet and decide all National Awards. National Awards will be announced at the end of June 2014.

National Awards Group EU Judging

Once all schemes outside of the UK have been submitted, the RIBA National Awards Group will meet and shortlist EU schemes based on the material provided.

If you are shortlisted you will be notified by the RIBA and a visit will be arranged where both the architect(s) and client will be asked to attend. If you are not shortlisted you will be notified in writing. We regret that at this stage feedback cannot be provided on individual entries.

Once all EU visits have been completed the RIBA Awards Group will meet and decide RIBA EU Award winners.

Criteria

Every judge will be asked to consider each of the following points in relation to every scheme. Before any visits are made, every judge will read and digest the criteria below (given in alphabetical order) and study all the submitted materials. They will then visit a building, look in detail at all its aspects, interior and exterior etc, listen to the story that both architect and client have to tell, interrogate them about the process and its results. After discussion with fellow judges, they will arrive at their provisional judgements. Once all visits have concluded, the jury will meet for a final time, take those provisional judgements, apply the criteria once again and decide their awards.

The judges are looking for buildings that fulfil as many of the criteria featured as possible; they will use their local knowledge and professional expertise to evaluate the relevance of the criteria to individual schemes and judge accordingly.

- Appropriateness of its structural and servicing systems
- Budget – value for money
- Capacity to stimulate, engage and delight its occupants, visitors and passers-by
- Complexity of brief / degree of difficulty - its architectural ambition and ideas
- Design vision. Is this reflected in all aspects of the design?
- Extent of innovation, invention and originality
- Fitness for purpose, especially in response to the client's brief as reflected in the level of client satisfaction
- Has it made a significant contribution to its immediate environment?
- Response to the issues of accessibility and other social factors
- Selection of materials and the way in which they are detailed
- Size/space – but not in terms of m2, the spatial experience it offers
- Sustainability – environmental and economic
- Timetable – the project should not have gone over time without good cause
- Type of contract e.g. traditional, design and build.

Key dates

Open for entries: 5 December 2013 (excl Scotland)

Entry closes: Friday 7 February midnight (excl Scotland)

For all queries relating to the awards entries you can contact:

RIBA Awards Office – 0207 307 3715

Regional offices:

RIBA London: 0207 307 5352

RIBA East: 01223 566285
RIBA East Midlands: 01522 837480
RIBA North East: 0191 2617441
RIBA North West: 0151 703 0107
RIBA South and South East: 0118 987 4900
RIBA South West and Wessex: 0844 800 2767