June 2010

Assessing Sustainability Principles in the Design of the Tate Modern Expansion

Alexander P. Nittel
Worcester Polytechnic Institute

Kristin Lynn Smith
Worcester Polytechnic Institute

Robert Nicholas Cakounes
Worcester Polytechnic Institute

Thaddeus Adams
Worcester Polytechnic Institute

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An Interactive Qualifying Project
submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfilment of the requirements for the
degrees of Bachelor of Science and Bachelor of Arts

by

_____
Thaddeus Adams

_____
Robert Cakounes

_____
Alexander Nittel

_____
Kristin Smith

Date:
16 June 10

Report Submitted to:

_____
Professor Robert Krueger, Primary Advisor

_____
Professor Nikolas K. Kazantzis, Co-Advisor

ABSTRACT

This report analyzes the prospects of environmental sustainability in the expansion of the Tate Modern museum in London. It does so with the comparison of the 2006 and 2008 BREEAM standards, and analysis of the innovative technologies in the Tate Modern, and an analysis of the prospects of LED lighting in art museums.

ACKNOWLEDGEMENTS

We would like to thank our sponsor, Jason Waddy, our advisors, Professor Krueger and Professor Kazantzis, everyone who contributed to our project through interviews, and lastly WPI for offering this educational experience.

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Written By: Kristin Smith

Edited By: Thaddeus Adams, Robert Cakounes, Alexander Nittel

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Written by: Thaddeus Adams

Edited by: Robert Cakounes, Alexander Nittel, Kristin Smith

Literature Review

Written by: Thaddeus Adams, Robert Cakounes, Alexander Nittel

Edited by: Thaddeus Adams, Robert Cakounes, Alexander Nittel, Kristin Smith

Methodology

Written by: Thaddeus Adams, Robert Cakounes, Alexander Nittel

Edited by: Thaddeus Adams, Robert Cakounes, Alexander Nittel, Kristin Smith

BREEAM Comparison

Written by: Robert Cakounes

Edited by: Thaddeus Adams, Alexander Nittel, Kristin Smith

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Written by: Thaddeus Adams

Edited by: Robert Cakounes, Alexander Nittel, Kristin Smith

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Written by: Alexander Nittel

Edited by: Thaddeus Adams, Robert Cakounes, Kristin Smith

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EXECUTIVE SUMMARY

Tate Modern adheres to its mission as a progressive, modern art museum. It does this by challenging social norms in the art it displays and in the design of the new expansion. Due to its popularity, Tate Modern seeks to use its expansion, Tate Modern 2 (TM2), to push other museums towards sustainability.

This report demonstrates ways to balance concerns of preserving its artwork, presenting its artwork, and achieving sustainability in Tate Modern. These three goals are in conflict with each other. To preserve and present artwork, a museum must adhere to strict, energy-intensive standards. To achieve sustainability, a museum must reduce energy consumption.

Tate Modern plans to use the Building Research Establishment Environmental Assessment Method (BREEAM) to evaluate its sustainability. BREEAM releases updated manuals every two years and includes manuals for educational facilities, health care facilities, and offices (BRE Global Ltd, 2009). However, TM2 does not fall into any of these categories. Thus, BREEAM has designed a bespoke manual exclusively for TM2, referencing 2006 BREEAM standards. Since the start of the expansion, a 2008 manual has been established providing newer standards.

This project addresses the conflict between sustainability, preserving art, and presenting art in three ways. We created a comparison of the 2006 BREEAM Bespoke Manual and the 2008 BREEAM Master Bespoke Manual, an in-depth report on Tate Modern's innovation, and an analysis of LED lighting. We addressed these topics in three stand-alone reports.

Section 1: 2006-2008 BREEAM Comparison

The comparison between the 2006 and 2008 bespoke manuals determines how TM2 could meet current standards. We conducted an analysis of the differences between criteria for each of the credits. We compiled a chart that documents the aim, the number of available credits, and the notable differences in each standard. We recommend which of the 2008 standards Tate Modern could achieve. We interviewed a BREEAM assessor to learn why BRE updated the BREEAM standards.

This report does not fully address the conflict between preserving art and maintaining environmental sustainability. This report ensures that the Tate Modern is implementing best

practices for environmental sustainability. Since this report deals largely with BREEAM standards, the concepts of preserving and presenting art are not relevant.

From our analysis, we determined that TM2 could achieve certain aspects of the 2008 standards. We addressed these aspects in the conclusion of **Chapter 4.**

Section 2: Innovation

This report determines the strengths and limitations of BREEAM with respect to innovation, how BREEAM is evolving with respect to recognizing innovation, and other avenues for gaining recognition for innovation. Tate Modern plans to use a desiccant dehumidification system, recycled waste heating system and a borehole cooling system. These three systems are a collaboration of old technologies being used in a new manner. We interviewed an engineer to better understand how the systems work. We also met with a BREEAM assessor to discuss the accreditation process for Tate Modern.

This report addresses the conflict between preserving and presenting art and maintaining environmental sustainability by analyzing a way that museums can be environmentally sustainable while maintaining proper conditions. This requires the use of innovative technologies that this report addresses. The complete conclusion of the report is found in **Chapter 6.**

Section 3: LEDs

The goal of this report was to analyze LEDs and determine prospects of their use in gallery lighting. We completed this through background research and interviews with professionals in the lighting and museum fields. We interviewed a curator and a conservator to further our understanding of why museums may or may not use LEDs in gallery spaces. By interviewing these individuals, we also determined gallery lighting requirements. We interviewed lighting specialists to help us understand the limitations and benefits of LEDs in more technical detail.

The report concluded that LEDs will be suitable for use in TM2. This is a way to preserve and present art properly while maintaining environmental sustainability. The conclusion is found in full in **Chapter 7**.

CHAPTER 1: INTRODUCTION

The goal of our project is to perform a critical assessment of BRE Environmental Assessment Methods and to challenge ideas surrounding the introduction of new technologies into museums, using Tate Modern as an example. We analyzed the tension between the energy-intensive design of a typical art museum and the need to be environmentally sustainable. This IQP approaches the tension from several different angles. These angles materialized into three reports.

The first report is in **Chapter 4.** This report is a comparison between the 2006 and 2008 BREEAM Assessors' Manuals. The purpose of this report is to determine key differences between the most current BREEAM standards and the standards that BRE will use to assess Tate Modern. The conclusion for this report shows how Tate Modern can maintain best practices for environmental sustainability. This addresses the tension by providing Tate Modern with a method to ensure it is an environmentally sustainable art museum.

The second report is in **Chapter 6.** This report is an analysis of BREEAM with relation to innovative features of Tate Modern. The purpose of this report is to determine if Tate Modern can gain recognition for its innovative features, and to determine strengths and limitations of BREEAM. This is accomplished through an analysis of BREEAM and LEED with respect to innovation at Tate Modern. The report concludes by showing the strengths and limitations of BREEAM, showing the way BREEAM is changing, predicting how BREEAM will change, and institutions that recognize innovation. This addresses the tension by providing an example of how museums can achieve accreditation and recognition for processes that increase the environmental sustainability of the museum and properly maintain art. This guidance is helpful to art museums that aim to be environmentally sustainable.

The third report is in **Chapter 7.** This report is an analysis of the benefits and barriers to implementing LED lighting in museums. The purpose of this report is to analyze the prospects of implementing LED lights in art galleries and art museums. This is accomplished through gathering perspectives of curators, conservators, and lighting specialists to determine the advantages and disadvantages of LED lighting. The conclusion of the report will determine how LED technology is advancing. This addresses the tension by creating an environmentally sustainable system that does not compromise museum standards.

This IQP will ultimately conclude what is necessary for an art museum to be environmentally sustainable, and determine if it is possible to be sustainable while preserving art properly.

CHAPTER 2: BACKGROUND CHAPTER

Museums have two main tasks with relation to the artwork they present. First is the actual presentation of the artwork. This usually involves aspects of lighting. To portray the art properly, the lighting must have an appropriate color temperature, color rendering and output (Fördergemeinschaft Gutes Licht, 2003). Color temperature deals with the color of the light source (Fördergemeinschaft Gutes Licht, 2003). Color rendering measures how much color the light reflects back (Fördergemeinschaft Gutes Licht, 2003). Second, the museum is concerned with preserving the artwork (Fördergemeinschaft Gutes Licht, 2003)

To do this, the museum controls the environment of the gallery. This involves the temperature, humidity and lighting of the room. Temperature control prevents the painting from expanding and contracting, which causes the paint to crack. Humidity control prevents the painting from absorbing excess water, causing the pigments to bleed. Lighting controls prevent the decay of pigments over time.

Preserving and presenting art properly is an expensive venture. For a light fixture to achieve the color rendering needed to display the artwork, the fixture needs to be less efficient than the commonly used counterparts. The temperature and humidity controls need to be running constantly to preserve the artwork. Typical heating units, such as gas furnaces, require either fossil fuels or an exorbitant amount of energy. These units emit pollutants such as NO_x and CO_2. Cooling systems also contain air conditioning units that use considerable amounts of energy. Typical dehumidification processes require the use of heating and cooling systems. For these reasons, the conventional museums are not seen as environmentally sustainable buildings.

As it expands, the Tate Modern will address the global movement towards sustainability. It will attempt to challenge the notion that art museums cannot be sustainable. The expansion to Tate Modern will follow the Building Research Establishment Environmental Assessment Method (BREEAM).This is a certification program for environmentally sustainable buildings. BREEAM is a robust assessment method. More details on BREEAM are found in **Chapter 4 and Chapter 6.**

Tate Modern is implementing processes that will make it more sustainable. These processes and technologies include recycled waste heat, borehole cooling, desiccant dehumidification, and LED lighting. The waste heat, borehole cooling, and desiccant

dehumidification processes use less energy and produce less pollution than other comparable systems. For more information on the innovative systems of Tate Modern, refer to **Chapter 6, section: "Innovative Technologies."** LED is an emerging technology that is less energy intensive than current lighting techniques. For more information, refer to **Chapter 7 "Prospects for LED Lighting in Art Museums".** The implementation of these processes is going beyond the boundaries of previous museum practices.

By achieving recognition as a sustainable building, Tate Modern will encourage the movement towards sustainable museums. By drawing upon its status as the most visited contemporary art museum, the Tate Modern expansion will have a significant influence on the sustainable museum movement.

To determine how Tate Modern is addressing the issue of becoming a sustainable building, it is important to gain an understanding of four key aspects relating to the expansion. These are:

1. The conflict between art preservation and environmental sustainability
2. The evolution of BREEAM standards
3. Innovation in relation to BREEAM
4. Prospects of implementing LED lighting

The following sections will explain these points and how they affect Tate Modern.

1.1: The Evolution of BREEAM Standards: Comparing 2006 and 2008 Manuals

BREEAM is an evolving system. In order to stay relevant, BREEAM updates its standards to match best practices. The leading contributor to these changes is UK legislation. The updates happen every two years.

Currently, the Tate Modern expansion is using the 2006 BREEAM Bespoke manual for its assessment. BRE designed Tate Modern's bespoke manual drawing from the 2006 standards. Since the original plans were established, BREEAM has created a newer set of standards.

Tate Modern desires to maintain best practices in environmental sustainability. As such, Tate Modern is looking to address the most modern standards. A comparison between the two manuals shows where Tate Modern can improve. The conclusion to the report in **Chapter 4 "Analysis and Comparison"** will show areas where Tate Modern can easily achieve 2008

standards and exceed the 2006 standards. In this way, Tate Modern will maintain best practice for environmental sustainability.

2.2: Innovation in relation to BREEAM

If a museum does not implement technologies that differ from typical museum practices, the museum will most likely not be environmentally sustainable. Tate Modern will use its innovative processes to achieve a higher state of environmental sustainability. These innovative technologies greatly reduce harmful emissions and energy use. The recycled waste heating system, borehole cooling system, and desiccant dehumidification system are responsible for zero NO_x emissions and minimal CO_2 emissions (Max Fordham Consulting Engineers, 2009). These processes are energy efficient and environmentally sustainable alternatives to conventional environmental controls.

It is important that Tate Modern gain recognition for environmentally sustainable features. Since BREEAM is the method used to assess Tate Modern, it is important to analyze BREEAM with respect to innovative technologies. This will help to determine what features of Tate Modern will gain recognition through BREEAM. This will also help to highlight some of the strengths and weaknesses of BREEAM. BREEAM may not recognize the effort that Tate Modern put forth. If this is true, Tate Modern can gain credit through other avenues.

The other avenues of recognition contain other environmental assessment methods and environmental profiles. **Chapter 6** analyzes one other environmental assessment method, LEED, and one set of environmental profiles that BRE publishes. LEED is an environmental assessment method that recognizes innovative methods. This is a reason to consider LEED standards when attempting to be environmentally sustainable. An analysis of LEED with respect to Tate Modern's innovation offers a perspective into why Tate Modern's processes are innovative. This analysis also offers justification for the implementation of the processes by recognizing that they are environmentally sustainable.

Even though BRE may not recognize innovation through BREEAM, the environmental profiles they publish contain specific information about the environmental impact buildings have. According to BREEAM Assessor 1, the details of Tate Modern's innovative features should be included in BRE environmental profiles.

2.3: Prospects for implementing LEDs

There is a tension to implementing LEDs in museums. This tension arises from perspectives of curators and the energy used to light an art museum or gallery. Curators and conservators can have the impression that LED lighting does not display the art as well as less efficient lighting techniques like halogen. This causes the curator or conservator to refuse to use LED lighting. This is a step in the wrong direction if a museum is striving to be environmentally sustainable.

Curators are concerned with several reputations LEDs have. White LEDs have a reputation for producing a cool, blue light with a high color temperature, according to Lighting Expert 1. In his opinion, early models were not effective enough for illuminating gallery spaces, both in terms of light output and in terms how well the light reflects color. These concerns about LEDs are analyzed and addressed in **Chapter 7.** Curators are usually conservative with their methods for maintaining and presenting the art. Halogen bulbs are established in the art world as the proper method for displaying art to its fullest potential. According to Lighting Expert 1, this is because halogen bulbs offer a high color rendering and are effective for spot lighting techniques. A conservative method for lighting ambient space is the use of high color rendering fluorescent lighting.

Tate Modern will look to challenge the status quo of using fluorescent tubes or halogen bulbs by implementing LED lit galleries. Some museums, such as the National Portrait Gallery, have already implemented trial LED lighting. Tate Modern is taking the next step in the movement for LED lighting by incorporating LEDs into the design for the expansion. Unlike other energy saving techniques planed for Tate Modern, the installation of LEDs can occur at any museum. Thus, Tate Modern hopes to encourage the use LEDs.

CHAPTER 3: METHODOLOGY

The premise of the project is to assess the sustainability of the Tate Modern expansion. Throughout the process, we gained an understanding of sustainability standards and analyzed how they pertained to the Tate Modern expansion. These applications include recommendations to help the Tate Modern be an environmentally sustainable museum.

The established research objectives were:

I. Comparison between 2006 and 2008 BREEAM standards;
II. Determination of how Tate Modern can gain recognition for innovation; and
III. Determination of prospects for LED lighting in gallery spaces.

We addressed each objective simultaneously.

For our interviews, we used semi-standard interviews that allowed us to have structured interviews, but also allowed us to change questions in the interview (Berg, 2007).

3.1: Comparison of 2006 and 2008 BREEAM Standards

Before going to London, we gathered information pertaining to standards that applied to the Tate Modern expansion and similar sets of standards. We analyzed the 2008 Master Bespoke Manual and the 2006 Bespoke Manual for Tate Modern.

An understanding of the key differences between the 2006 bespoke standard and the 2008 standard is necessary. Substantial differences exist between these two standards. Our task was to determine what these differences are and how they affect the Tate Modern's expansion.

The first part of our analyses involved forming a table comparing the BREEAM 2008 manual and the 2006 BREEAM Bespoke Manual. We compared the individual chapters of each standard, and we noted the aim of the sections, the number of credits that could be earned, and the notable differences in a table.

Next, we analyzed these differences in a report, noting aspects of the 2008 standards that Tate Modern can apply to the expansion. The analysis report addresses three major issues. What changed, why it changed, and how the change affects the expansion project. The analysis report is in **Chapter 4** along with the comparison table.

We interviewed a BREEAM assessor to gain further insight into the key differences between the 2006 bespoke standard and the 2008 standard, as well to understand the assessment process better.

3.2: Determination of How Tate Modern can Gain Recognition for Innovation

The first step in determining how Tate Modern can gain recognition for its innovative processes involved understanding what Tate Modern's innovative processes were. In order to do this, we analyzed technical documents that contained information on Tate Modern's technologies. We also interviewed an engineer who is working on Tate Modern to gain an understanding of how the technologies worked and why they are innovative.

We analyzed three innovative technologies at the Tate Modern. These technologies include the recycled waste heating system, the borehole cooling system, and the desiccant dehumidification system. The analyses of these systems determine how the systems operate. The analyses of these systems also determine why they are environmentally sustainable and why they are innovative technologies.

In order to determine how Tate Modern can gain recognition, we identified institutions that recognize innovation. The three systems we analyzed were the BREEAM 2008, the BRE Green Guides, and the LEED 2009 assessment method. We also analyzed the 2006 BREEAM manual that is going to be used to assess Tate Modern. The analyses of these systems determine how the systems recognize innovation and how they could recognize it better. In addition to analyzing the reports, we interviewed a BREEAM assessor to gain his perspective on how Tate Modern could be recognized for its innovation. He clarified how BREEAM recognizes innovation, and where Tate Modern could gain points in a BREEAM assessment.

With the information gathered, we developed a report that draws attention to the way BREEAM assesses site specific and innovative technologies, using Tate Modern as a case study. The report means to highlight strengths and limitations of BREEAM, demonstrate how BREEAM is evolving to recognize innovation better, and determine other institutions that recognize innovation. This report is found in **Chapter 6.**

3.3: Analysis of LED Lighting and Determination of Prospects in Gallery Lighting

Throughout our research, we determined the barriers to art museums lighting galleries with LEDs. We conducted background research to gain an understanding of how LED lighting works.

We conducted research to find museums that had implemented LED lighting. One museum that had tried LED lighting was the Worcester Art Museum. We conducted an interview with the facilities manager at the Worcester Art Museum to gain an understanding of his experience with LED lighting. The National Portrait Gallery had two rooms with LED lights. These museums' experiences were used to develop case studies of LED lighting.

We contacted many museums' curators in London with requests for interviews. These interviews gave us a better understanding of why LED lighting may or may not be used, through multiple perspectives.

We interviewed lighting specialists to gain an understanding of the prospects of using LED lighting from a different perspective. First, we interviewed Lighting Specialist 1. The interview with the lighting system designer helped us to understand benefits and limitations of LED lighting to an extent that was not available or found through background research. Next, we interviewed Lighting Specialist 2 at a manufacturer of LEDs. He told us where LEDs stand in comparison to other lighting techniques and where the industry is heading in the near future.

Using the background information we found, and the opinions of interviewees, we developed a report on LED lighting. This report lists the different perspectives of the people interviewed. It determines if LEDs are suitable for gallery lighting. This report can be found in **Chapter 7.**

3.4: Summary

In summary, through interviews, site analyses, and evaluating building standards, we created three reports. One is a comparison between the 2006 bespoke and 2008 BREEAM standards. The second is an analysis of how Tate Modern can be recognized for its innovation. The third is a critical analysis of the prospects for LED lighting in art galleries.

The next three chapters - Chapters 4, 6, and 7 - of the report are our findings. Each chapter is a stand-alone report. These reports will be distributed to their intended audiences as independent documents.

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Analysis and Comparison

2006 BREEAM BESPOKE MANUAL WITH 2008 BREEAM MANUALS

By: Robert Cakounes,

Edited By: Thaddeus Adams Alexander Nittel, Kristin Smith

24 June 2010

The goal of this document is to provide a comprehensive analysis and comparison of the 2006 Bespoke Manual established for the expansion of Tate Modern with current BREEAM Master Bespoke Assessors manual. The document will address how the changes affect Tate Modern and provide recommendations to where Tate Modern can achieve the current standards.

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Introduction

Tate Modern was built to hold 1.8 million visitors annually. However, 4.8 million visitors travel to Tate Modern ever year. Due to this, it was decided that Tate Modern needed to expand. In addition, the expansion project will attempt to achieve best practice for environmental sustainability. The expansion project is titled TM2.

To accomplish this goal, Tate Modern seeks accreditation from the Building Research Establishment (BRE) for the expansion project. BRE is a nongovernmental body that regulates best practices for buildings. Building Research Establishment Environmental Assessment Method (BREEAM) establishes best practices for the construction of sustainable buildings. In 2006, Tate Modern applied for a BREEAM Bespoke Assessor's Manual. BRE creates bespoke, or custom, manuals for buildings that do not fit under the established manuals. BRE updates the Master Bespoke Manual every two years. This means Tate Modern's Bespoke Manual is currently out of date. In an attempt to keep best practices for environmental sustainability, Tate Modern will address these new standards.

This report will determine if the Tate Modern expansion could achieve the 2008 BREEAM bespoke accreditation. To this end, a comparison of the major differences between the 2008 BREEAM standards and the 2006 BREEAM standards will follow. This report will conclude with recommendations for 2008 credits that are achievable by Tate Modern.

This document will consist of the major points of interest to TM2. As such, it will not include every change in criteria, only criteria that are most likely to affect the expansion project. The report will not address standards and criteria that remained the same between the two years. To view a full list of the comparison of standards, please view the attached document **A Comparison of BREEAM 2006 and 2008**.

Maintaining Relevant Standards

BRE updates the BREEAM Manuals every two years. In addition, BRE mandates that when a new manual is released, buildings being assessed by earlier manuals have five years to complete construction. Since BREEAM assessed TM2 with the 2006 standards, the expansion must finish by 2013. These regulations ensure that the manuals, and the build, are consistent with best practices. There are two main factors that attribute to the updates in BREEAM manuals.

The first factor is UK legislation and policy papers. Legislation is the largest contributor for updates. For example, the update to the "Reduction of CO_2 Emissions" standard is due to the introduction of the legislation "Energy Performance Certificate." The changes to the "Provision of Public Transport" standard are due to "Transport Assessment Best Practices." This is a policy paper released by Transport For London.

The second factor is foreign assessment methods. BRE adopts standards from sustainable buildings schemes such as the United States Green Building Council: Leadership in Energy and Environmental Design (USGBC:LEED) and the French Haute Qualité Environnementale (HQE). The introduction of the "Innovation" section is to relate closer to LEED, which awards credit for innovation in some standards. According to BREEAM Assessor 1, it would not be surprising if there are aspects of LEED in the 2010 or 2012 BREEAM Manuals. One of these aspects is the introduction of site-specific standards.

Major Differences throughout the 2008 BREEAM Bespoke Manual

Most of the differences between the BREEAM assessors' manuals are the specific criteria one must meet to obtain credits. However, there are differences in the BREEAM manuals that are universal to all standards. There are three changes that impact Tate Modern if Tate Modern chooses to achieve 2008 standards.

The first change is in the weighting scheme. Each section is weighted a certain percent, all summing to 100%. According to BREEAM Assessor 1, the industry deemed the old weighting schemes were out of date and thus developed the new standards. One area to note is the "Materials and Waste" section. This section was a single section in 2006; however "Materials" and "Waste" are now separate sections. Another major change deals with the "Energy and Transport" sections. In manuals preceding 2008, these two sections were scored and weighted as one section. In 2008, they are scored weighted separately. A section-by-section overview will assess how the 2008 changes affect the Tate Modern expansion process. **Table 13** compares the two weighting systems and the current score for Tate Modern.

The second difference is the establishment of mandatory post construction regulations. These regulations are in addition to the current planning and procurement regulations. The purpose of the post construction regulations is to ensure companies follow the assessed designs. These regulations are optional in 2006.

Lastly, there is the introduction of "Minimum Standards." These requirements are additions to the existing standards. "Minimum Standards" prevent a building from achieving a higher grade unless it addresses key issues. For example, if the contractors only wish to achieve the minimum grade of "Passing", three "Minimum Standards" need addressing. These are in the "Commissioning," "High Frequency Lighting," and "Microbial Contamination" standards. However, to achieve the next highest grade of "Good" five "Minimum Standards" need addressing. The two additional standards are "Water Consumption" and "Water Meter".

The following sections discuss the changes within each set of standards. Each standard will have the goal and how to achieve the credits stated first. Then there is a brief description of why the standard was changed. Lastly, the report includes a description of how these changes affect Tate Modern. The project will conclude with the effects on and recommendations for the Tate Modern.

Management

The Management sections of both the 2006 and 2008 deal with the management of the construction and the running of systems in the building. The section has standards on the construction site, the proper use of consultants, and the developing of the building as a centre of learning.

Table 1: Points of Interest for 2006 Management Section

Credit Title	Description
Commissioning	To ensure an appropriate project team member is placed in control of commissioning. That all commissioning follows Building Regulations and best practices. The origination places the specialist in charge of complex systems, i.e. air-conditioning and mechanical ventilation. In addition, the building demonstrates seasonal commissioning.
Post-Construction testing—Acoustics	A post-construction acoustic testing will determine the acoustic performance of the building, showing agreement with the acoustic design specifications. The design specifications used are based on the Health and Wellbeing standard, "Acoustic Performance."

Table 2: Points of Interest for 2008 Management Section

Credit Title	Description
Commissioning	To ensure an appropriate project team member placed in control of commissioning. That all commissioning follows Building Regulations and best practices. **Special emphasis placed on Building Management Systems (BMS).** The origination places the specialist in charge of complex systems, i.e. air-conditioning and mechanical ventilation**.** In addition, climate controls are tested over a 12-month period under all extremes and loads.
Post-Construction testing—Acoustics	*BRE remove this section due to the introduction of post-construction regulations.*

The Commissioning standard differs by the addition of the rule Building Management Systems (BMS). The conventional BMS control 60% to 80% of the building's mechanical and electrical systems. A properly commissioned BMS can also reduce the energy demand of the 33building. The criterion mandates that the BMS is the first functional system in the building. In addition, the section states that the system needs to be operational and tested before the engineers hand the building over.

BRE increased the criteria in the commissioning section due to improper commissioning of BMS. BRE updated this standard to keep with best practices for BMS. These practices ensure the proper commissioning of the BMS and therefore reduce energy demand.

Tate Modern must address the extra criterion in the commissioning standard. This is due to the use of a BMS within Tate Modern expansion. The proper commissioning of a BMS reduces the energy consumption of the building. Therefore, it is important for Tate Modern to stay relevant on best practices for BMS. The implementation of the criterion does not need to happen until the building is near completion. Thus, Tate Modern has ample time to address the concerns about the commissioning of the BMS.

The Post-Construction testing—Acoustics credit does not appear in the 2008 manuals. This is due to the introduction of post-construction regulations throughout the 2008 manual. The credit is now the post-construction regulation for the Health and Wellbeing, Acoustic Performance credit.

The reduction of this credit in the management section has minimum impact on Tate Modern. The main concern is that a credit was once optional is now mandatory. However, the criteria to achieve the credit have not changed. To achieve the credit, acoustic testing must demonstrate compliance with the design specifications developed for the Acoustic Performance credit.

Due to the adjustment of the weighting, the importance of the Management section goes down from 15% in 2006 to 12% in 2008. This affects Tate Modern negatively since Management is the strongest section in the TM2's current assessment with 79% of possible points.

Health and Wellbeing

This section of the 2006 and 2008 manuals deal with maintaining the health and wellbeing of employees and visitors to the building. To do so the section puts emphasis on ensuring natural lighting to the building, providing a view of the landscape, and control over indoor air quality.

Table 3: Points of Interest for 2006 Health and Wellbeing Section

Credit Title	Description
Lighting Zones	This credit maximizes the level of user control over lighting within each workspace.
Lighting Controls	To ensure that commonly used lighting systems are easily assessable by building occupants.
Indoor Air Pollution	Demonstrates that air intake and outlet sources are over 10 meters apart and the intake is over 20 meters from external pollution. All openable windows are 10 meters away from external sources of pollution.
Indoor Air Quality	To demonstrate a system that monitors CO_2 in areas with unpredictable user amount. The system must be able to automatically adjust the amount of fresh air in the area, or contact the building owner / manager.
Ventilation Rates	This credit demonstrates that all areas of the building have the recommended minimum amount of fresh air. The ventilation rates are a minimum of 12 litres per second per person.
High Frequency Lighting	This Credit intends to increase the use of high frequency lighting in work areas. High frequency fluorescent lighting reduces the irritation due to flickering and humming that is common with conventional fluorescent lighting. Corridors and pathways do not need to use high frequency lighting

Table 4: Points of Interest for 2008 Health and Wellbeing Section

Credit Title	Description
Lighting Zones and Controls	This credit ensures that all building users and occupants have easy and assessable control over lighting within each relevant building area. *This credit is a combination of the previous Lighting Zones and Lighting Controls credit.*
Indoor Air	***This Credit is a combination of the 2006 Indoor Air***

Quality	*Pollution, Ventilation Rates, and Indoor Air Quality*
High Frequency Lighting	This Credit intends to increase the use of high frequency lighting in work areas. High frequency fluorescent lighting reduces the irritation due to flickering and humming that is common with conventional fluorescent lighting. **All areas must use high frequency lighting.**

The "Lighting Zones" and "Lighting Controls" standards are combined in the 2008 standards. There are no changes to the criteria need to achieve the 2008 "Lighting Zone and Controls" standard.

The changes BRE made to this section will not affect Tate Modern. Even though a credit is lost with the new standards, none of the criteria changed. Therefore, a BREEAM assessor would assess Tate Modern equally in the new system.

Indoor Air Quality is a combination of multiple standards. The 2006 credits involved are Indoor Air Pollution, Ventilation Rates, and Indoor Air Quality. The criteria for the 2008 Indoor Air Quality credit have no new additions to the 2006 credits that comprise it. The change results in the loss of two credits.

The changes BRE made to this standard will have a negative effect on Tate Modern. Tate Modern is not expected to receive the Indoor Air Pollution standard. Therefore, under the new system, Tate Modern would lose all credit in this standard. There is no way for Tate Modern to address this issue.

The High Frequency Lighting section in 2008 mandates increased use of high frequency lighting. In 2006, the standard is achieved by having high frequency lighting in spaces that will be occupied for long periods of time. This means office spaces, lobbies, and dining rooms. To achieve the standard in 2008 all spaces must use high frequency lighting. In addition to the areas above, stairwells and hallways must also use high frequency lighting.

This standard was changed to decrease the irritation of fluorescent lighting. Low frequency fluorescent lighting flickers and makes a humming noise as it switches on and off. High frequency fluorescent lighting solves the flickering problem by switching on and off at a faster rate than the human eye can detect. The sound produced is above the audible range. In addition, high frequency lighting is 10% more efficient than low frequency lighting.

Tate Modern already achieves this standard. The current plans for TM2 use high frequency for all fluorescent lighting.

The weighting scale between the 2006 and 2008 assessment methods for this area remained unchanged, staying at 15% in both years. As such, the change does not affect the expansion of Tate Modern.

Energy

This section deals with the emissions and use of power in the building. It has the single largest amount of available credits out of any of the chapters in either manual, awarding 15 credits for "CO_2 emission." This chapter also includes the installation of sub-metering systems, and in the 2008 manual includes sections on "low carbon technologies" and "building insulations and quality of air filtrations".

Table 5: Points of Interest for 2006 Energy Section

Credit Title	Description
Reduction of CO_2 Emissions	This standard encourages the development of low emission building. To do so, the building must demonstrate capability to show a percent improvement on an existing benchmark. Credit is awarded to the build for higher percent improvement up to fifteen points.
External Lighting	This standard encourages the use of energy efficient lighting in the lighting of external spaces. One must demonstrate the use of 80% of external lighting and must be above 100 lamp lumens/ circuit Watt.

Table 6: Points of Interest for 2008 Energy Section

Credit Title	Description
Reduction of CO_2 Emissions	This standard encourages the development of low emission buildings. To do so, a comprehensive computer model of the building is constructed using ideal and actual specifications. The BREEAM assessor makes a prediction for the CO_2 emissions for both building types. The BREEAM assessor awards credits, up to fifteen, by comparing the ideal emissions to actual emissions.
External Lighting	This standard encourages the use of energy efficient lighting in the lighting of external spaces. This includes specialization of areas, and requirements that include colour rendering. For example: 1. Lighting for the building, access ways, and pathways use 50 lamp lumens/ circuit Watt with colour rendering greater than or equal to 60; 2. Lighting in car parking lots, associated roads, and floodlighting must have an efficiency of 70 lamp lumens / circuit Watt and colour rendering greater than or equal to 60.

	A complete list of requirements is on page 133 of the 2008 BREEAM Master Bespoke Manual.
Low or Zero Carbon (LZC) Technologies	This standard aims to reduce emissions produced from occupying the building. It does this by encouraging the use of LZC technologies. These technologies generate renewable energy. This energy must supply a substantial portion of the energy demand to the building. A complete list of requirements is on page 136 of the 2008 BREEAM Master Bespoke Manual. **This section is found in the Pollution section of the 2006 Bespoke manual, as the Renewable & Low emission Energy Credit**
Building fabric performance and avoidance of air infiltration	This standard aims to reduce the heat loss in the building as well as reduce the amount of air infiltrations. To accomplish this, the design plans show the use of doors between internal and external areas. All bay doors take less than five seconds to close. Other requirements are page 142 of the 2008 BREEAM Master Bespoke Manual.

Reduction in CO_2 standard changed greatly between the 2006 and the 2008 manual. Although the main goal of the credit is the same, the process to achieve the credit has changed. To achieve the credit in 2006, the design team needed to prove through computer modelling that the emission standards are a certain percent above a benchmarked standard. However, in 2008, the BREEAM assessor creates two computer models of the proposed building. One model uses ideal materials and specifications, the other uses actual data. The assessor then takes a ratio of the two numbers. This value is then compared to benchmark standards, and credit is awarded based off the ratio.

BRE changed this section due to the introduction of the Energy Performance Certificate (EPC) legislation in 2008. It requires all commercial buildings to obtain an EPC when built, rented or sold. BRE based the CO_2 calculation method for the 2008 BREEAM Manual off this legislation. The EPC awards a grade between "A" and "G." The 2008 BREEAM Manual assigns each grade a credit value.

This update will negatively affect Tate Modern. According to BREEAM Assessor 1, the 2006 and 2008 values for this section are not directly comparable. The assessor states that a building will score similarly under both standards, however, in his experience, buildings usually score lower under the 2008 standards.

The External Lighting section became more specific in the 2008 manual. The 2006 Bespoke Manual says, "80% of external lighting must be 100 lamp lumens / circuit Watt." The 2008 manual breaks down the external lighting into areas such as car parking lots, access ways, and associated roads. Then it provides regulations on the lighting system. For example, lights in car parking lots must have an efficiency of 70 lamp lumens / circuit Watt. In addition, the 2008 manual has regulations on colour rendering. Above are examples of the regulation, and location of the full regulation.

The changes to the External Lighting section have a minor affect on the expansion project. This is because the project has not purchased finish products. *The issue arises with achieving the credit in 2006*. Since the 2008 requires lower efficiency lighting, an attempt to switch to the more current standards might save the project money. However, updating the standard would end in the loss of credit in the 2006 Bespoke Manual.

The Low or Zero Carbon Technologies (LZC) standard deals with the use of renewable energy systems in and around the building in question. To achieve this credit, the project team must conduct a feasibility study to determine the most appropriate local LZC source. The organisation that is in control of the building can choose to supply the building with 100% renewable energy for the first three years of the building's use to achieve the first credit. Two more credits are possible to achieve through this standard. The instillation of a LZC in the proposed building is necessary to achieve these credits. BREEAM awards one credit for a 10% reduction in CO_2 and two for a 15% reduction. BREEAM awards an exemplary credit for a system that reduces CO_2 by 20%.

The change will have a positive effect on Tate Modern. This is due to the loss of credits in the "Reduction of CO_2 emissions" credit. The criteria for the "Low or Zero Carbon Technologies" standard is the same as the "Renewable & Low emission Energy" standard from the pollution section of 2006 standards. TM2 is currently estimated to receive two credits here. The addition of these credits in this section might help to offset the credits lost.

Building fabric performance and avoidance of air infiltration standard is absent from the 2006 manual. This credit attempts to minimize heat loss from the building. It does this by putting increased regulations on external doors. For example, insulation is present on every personal door between internal and external spaces and that every bay door must close in under five seconds.

The addition of this standard is because of the "UK Energy Bill." This bill aims to reduce CO_2 emissions by 60% by 2050 (Regen SW, 2007). In addition, the bill notes that 50% of the CO_2 emissions arise from heating buildings. BREEAM added this category into the energy section to alleviate the emissions from heating buildings.

Achieving this credit would most likely have a positive effect on TM2. Most of the aspects of the credit come from choosing finish products that are heavily insulated. Although these products might have a higher initial cost, the payback period in the reduction of heat lost could have a positive effect.

The weighting scale changed substantially for energy. In 2006, the BREEAM Manual weighted Energy and Transport together, for 25%. In 2008, BREEAM made Energy independently weighted, at 19%. With the combined scoring system in 2006, it is difficult to determine the affect the new weight will have on Tate Modern. However, the estimated score for the project scored Energy higher than transport. Therefore, the separation might have a positive impact on Tate Modern.

Transport

The main objective of this section is to encourage the use of sustainable transport. This includes the use of public transport, bicycles or other manual methods, and minimal use of parking for private vehicles.

Table 7: Points of Interest for 2006 Transport Section

Credit Title	Description
Provision of Public Transport	This credit deals with the proximity to public transport nodes. BRE assigns credits based on the distance, and frequency of public transport vehicles, i.e. buses and trains.
Pedestrian and Cyclist Safety	This standard acts to minimize the risk to pedestrian and cyclists. The standard sets a minimum width for bike paths and pedestrian walkways. *Specific numbers change*

Table 8: Points of Interest for 2008 Transport Section

Credit Title	Description
Provision of Public Transport	This credit deals with the proximity to public transport nodes. BRE assigns credits based on the distance, **number**, and frequency of public transport. **In addition, BREEAM considers the average wait time, walk time, and the quality of public transport; trains rate higher than busses.**
Pedestrian and Cyclist Safety	This standard acts to minimize the risk to pedestrian and cyclists. The standard sets a minimum width for bike paths and pedestrian walkways. *Specific numbers change*

The update to "Provision of Public Transport" standard introduces the" Accessibility Index" (AI). The 2006 Bespoke Manual used a "Frequency Table." This table considers how far away and how often public transport vehicles arrive at transport nodes. The AI is a calculation method that includes frequency, distance, walk time, wait time, and quality of transport.

BRE updated this standard due to the release of "Transport Assessment Best Practices" in May of 2006 (Transport For London, 2006). This document was released by Transport For London. BRE modelled the AI off the Public Transport Accessibility Level (PTAL). BREEAM 2008 credit is based on the score on the PTAL.

This change could be problematic to Tate Modern. This credit is out of the control of Tate Modern. If Tate Modern was assessed using 2008, it is possible for it to score lower. This is because the AI addresses the number, walking time, and the walking time for local public transport nodes, not just the frequency at the closest node.

"Pedestrian and Cyclist Safety" standard update shows a change in specific numbers in the criteria. The overall goal of the standard is the same. A main difference is that in 2008 cycle paths can be a part of carriageways, with a minimum of 1.5 M provided for the cycle path. In 2006, this was not allowed. The minimum standards for cycle and pedestrian pathways increased. The standard in the 2008 Master Bespoke has cycle paths at a minimum of 2.0 M wide, while the minimum in 2006 was 1.5 M.

BRE updated this standard to comply more closely with the "National Cycle Network Guidelines and Practical Details" (BRE Global Ltd, 2008). These guidelines were introduced to promote cyclist safety in 1997. The 2006 regulations were based off the "Shared Use Routes" (BRE Global Ltd, 2006). Both of these documents are produced by the same organisation, Sustrans. The "National Cycle Network Guidelines and Practical Details*"* are currently accepted as best practices.

Since the expansion to Tate Modern is currently not expected to receive this credit, the changes made will have minimal effect on the expansion. Updating to reach these criteria is also costly. This is because Tate Modern has limited space and the design portion has already passed.

The weighting scale changed substantially for energy. In 2006, BREEAM weighted Energy and Transport together, for 25%. In 2008, Transport is independently weighted, at 8%. With the combined scoring system in 2006, it is difficult to determine the effect the new weight will have on Tate Modern. However, the estimated score showed Transport scoring lower than Energy. Therefore, the separation might have a positive impact on Tate Modern.

Water

The water chapter addresses the consumption and detection of water in the buildings. It deals specifically with how the building should address water consumption. For example, standards address use per person or specific technologies and the leak detection systems, including automatic shutoffs.

BRE made no changes in criteria that affect Tate Modern, or that Tate Modern could address to stay current.

The weighting scale between the 2006 and 2008 assessment methods for this area remained relatively unchanged, from 5% in 2006 to 6% in 2008. As such, the change does not affect the expansion of Tate Modern.

Materials and Waste

The chapter of Materials and Waste addresses the re-use of building structure, building elements, landscaping, waste storage, et cetera. In the 2008 manual, Waste and Materials are separate chapters. The separation of these sections greatly affects their weighting.

Table 9: Points of Interest for 2006 Waste and Materials Section

Credit Title	Description
Insulant	*This credit is in the Pollution section of the 2006 manual. However, it closely resembles the Insulation credit in the 2008 manual.* The credit ensures that all insulations used have a Global Warming Potential under five.

Table 10: Points of Interest for 2008 Waste and Materials Section

Credit Title	Description
Insulation	This credit relates most closely to the Insulant credit from the 2006 manual. **This credit however, contains regulations from the "Green Guides."** The credit is achieved by receiving a grade of "A" in the "Green Guides." **A second credit is available if the insulation used is properly sourced.**
Construction Site Waste Management	**This standard is new to the 2008 manual.** The goal of this standard is to minimize the amount of construction waste. BREEAM gives more credits for less of an impact.

BREEAM uses "Insulant "and "Insulation "credits to guarantee that the types of insulation used have a minimal impact on the environment. The 2006 manual accomplishes this by enforcing the use of materials that have a Global Warming Potential under five. The "Green Guides," that are now part of the BREEAM assessment, accomplish the same task. BREEAM gives credit by determining the weighted thermal resistance, which is calculated by:

a. (Area of insulation (m^2) * thickness (m)) / Thermal Conductivity (W/ m.K) **OR**

b. Total volume of insulation used (m^3) / Thermal conductivity (W/m.K)

The type of insulation is then rated by the "Green Guides" and given a grade between "A" and "E." This grade correlates to a number. For example, a grade of A is 3 points. Lastly, the

BREEAM assessor multiplies the two numbers together. The amount of credit is awarded based on this value.

BRE removed the standard from the Pollution section to reduce redundancy. With the introduction of the "Green Guides," having a separate criterion for building materials in the pollution section is redundant.

Since the installation of insulation at Tate Modern has not happened, there is still time to address this criterion. The expansion project expects to achieve credit for the "Insulant" standard in 2006. It is likely that Tate Modern already achieves the modern standard. However, it could be in Tate Modern's best interest to look into the criteria. It is also useful to investigate the prospects of achieving the second credit.

BREEAM introduced the "Construction Site Waste Management" credit to encourage the reduction of construction waste. The credit sets a standard amount of waste per 100 m^2. One credit is achieved by having 13.0-16.6 m^3 of actual volume and 6.6-8.5 tonnes of waste; two credits for 9.2-12.9 m^3 and 4.7-6.5 tonnes; three credits for less than 9.2 m^3 and less than 4.7 tonnes.

BRE added this credit due to the UK legislation "The Site Waste Management Plans Regulations." This legislation places strict regulations on the waste produced on site. The BREEAM standard awards one credit for the minimum regulations. Additional credits are awarded for exceeding the legislation's regulations.

Tate Modern should see if it is feasible to achieve the excess credits. The expansion project has been keeping track of the waste created. This information can be use to determine if Tate Modern is able to achieve the excess credit.

Due to the weighting change and the separation of sections, Tate Modern would be hurt by the Materials and Waste sections. This is because the Waste section is weighted at 7.5% and the Materials section is 12.5%, totalling 20% of the total score for the assessment. The Materials and Waste section is weighted at 10% in the Bespoke 2006 manual. Since Tate Modern is not scoring well in this section—37.80% of total points possible—this increase is not beneficial to the expansion project.

Land Use and Ecology

The Land Use and Ecology section is meant to minimize the impact on the immediate ecosystem. The credit focuses on the re-use of land, contaminated land, enhancing site ecology, and the long-term impact on biodiversity.

BRE made no changes in criteria that affect Tate Modern, or that Tate Modern could address to stay current.

Due to the changes in the weighting system, there is less emphasis on these criteria. It decreases from 15% in 2006 to 10% in 2008. This affects Tate Modern positively since its score is low in this section, 47.50%.

Pollution

The goal in the Pollution section is to minimize the pollution created during the lifetime of the building. In the Pollution chapter, issues addressed are refrigerant Global Warming Potential (GWP), preventing refrigerant leaks, minimizing flood risks, and the reduction of night-time light pollution.

Table 11: Points of Interest for 2006 Pollution Section

Credit Title	Description
Renewable & Low Emission Energy	This standard aims to reduce emissions produced from occupying the building. It does this by encouraging the use of LZC technologies. These technologies generate renewable energy. This energy must supply a substantial portion of the energy demand to the building. A complete list of requirements is on page 39 of the 2006 BREEAM Bespoke Manual for Tate Modern. **This section is found in the Energy section of the 2008 Master Bespoke Manual, as the "Low or Zero Carbon Technologies" Credit**
Insulant GWP	The credit ensures that all insulations used have a Global Warming Potential under five. *BRE moved this credit to the Materials section in the 2008 manual. The new section is titled "Insulation"*
(Minimising) Flood Risk	*BRE designed this credit to demonstrate the building's ability to minimize flood damage.* To accomplish this, the building must determine the range of annual flood risk, low medium or high. Depending on the risk, the design accomplished certain aspects to ensure the safety of the building.

Table 12: Points of Interest for 2008 Pollution Section

Credit Title	Description
(Minimising) Flood Risk	The criteria is the largely the same as the 2006 criteria. The new standard includes the use of Flood Risk Assessments (FRA) to confirm the risk of the area.

READ THE ENERGY CHAPTER, PAGE 22, FOR AN ANALYSIS OF THE "RENEWABLE & LOW EMISSION ENERGY" CREDIT.

READ THE MATERIALS CHAPTER, PAGE 26, FOR AN ANALYSIS OF "INSULANT GWP" CREDIT.

The (Minimising) Flood Risk changes with the introduction of FRAs for all risk zones. These assessments are used to assess the likelihood of a flood in the area of the building.

This change has no affect on Tate Modern. This is because Tate Modern is in a high-risk flood zone. As such, this assessment was already completed. Tate Modern can do nothing to address the new standard.

The Changes in the weighting system places less of an emphasis on these criteria. This is due to a decrease in weighting from 15% in 2006 to 10% in 2008. This is a positive change for Tate Modern because this section is the third lowest rated section, at about 64% accreditation.

Conclusion

The 2008 Master Bespoke Manual affects Tate Modern's expansion in different ways. First, there are administrative changes throughout the manuals that move or combine standards. Second, there are changes to the format and weighting of BREEAM. Third are changes to actual criteria in each standard.

Most of the administrative changes to the manual will not affect TM2. This is because criteria did not change. However, one instance that this affects Tate Modern is the "Indoor Air Quality" standard. Since this standard is now the combination of three credits from 2006, one of which TM2 will not receive credit for, Tate Modern would not receive any credit for this standard in 2008. Tate Modern cannot address this concern

The most severe changes are the format and weighting changes. This is due to the increased importance of the "Materials and Waste" section. Since "Materials and Waste" is Tate Modern's weakest section, the increase of importance, to 20% of the total score from 10%, is difficult to overcome. Tate Modern cannot address this concern.

There is *one credit Tate Modern can address; however doing so will contradict the 2006 standards*. This Credit is the "External Lighting" standard. The standard in 2006 calls for the use of 80% of 100 lumens / watt for external lighting. The 2008 standard gives credit for having lower efficiency lighting, in specific areas. Tate Modern can address this credit and potentially save capital. Since Tate Modern has opted to have post-construction testing on this section, updating the standard may result in a loss of credit. Discussion with the BREEAM assessor should be conducted to address this issue.

Certain aspects of the update Tate Modern can easily address and it will not affect the current standings of its accreditation. These standards are "Commissioning," "High Frequency Lighting," and "Insulation."

To comply with the 2008 "Commissioning" standards Tate Modern needs to implement a procedure that encourages the proper use and activation of the BMS used at TM2. Since a properly commissioned BMS saves more energy, it is in Tate Modern's best interest to ensure proper usage of a BMS. By following the 2008 regulations, Tate Modern will ensure that the expansion follows best practices.

The "High Frequency Lighting" standard in 2008 requires all spaces to use high frequency fluorescent lighting. Since Tate Modern s already implementing 100% high frequency lighting, it has already achieved this improved standard.

The "Insulation" credit ensures the insulation used has a low environmental impact. This credit resembles the "Insulant" credit from 2006. Tate Modern has already achieved this criterion. However, 2008 contains regulations on the amount of insulation used. It also includes an optional secondary credit. The secondary credit states that 80% of the insulation used must be responsibly sourced. Addressing this concern could reflect on Tate Modern favourably.

Two credits are not addressed in the 2006 standards that Tate Modern should attempt to achieve. These sections are the "Construction Waste Management" and "Building Fabric Performance and Avoidance of Air Infiltration." BREEAM introduced these due to changes in legislation.

To achieve the first credit in the "Construction Waste Management" standard a building must comply with established legislation. BREEAM offers additional credit for going above this criterion. Since previous standards enforce the monitoring of waste, Tate Modern can predict the amount of waste the site will produce. From here, Tate Modern can determine if achieving the second or third credit is feasible.

The "Building Fabric Performance and Avoidance of Air Infiltration" credit means to decrease heat loss through openings in the building. Doing so will decrease the energy needed to heat the building. Although this credit is not directly linked to legislation, it is based off the "UK Energy Bill" which aims to reduce energy consumption by 60% by 2050. Not all of the criteria mentioned may be obtainable to Tate Modern at this stage. The credit does address some finish products which Tate Modern can implement.

In summary, it is not feasible for Tate Modern to file for assessment under the 2008 methods. This is due to changes in the assessment method that are out of the control of Tate Modern. However, there are aspects of the 2008 methods that Tate Modern can address to maintain best practices for environmental sustainability. To do so, Tate Modern can address the finish products for the expansion, as well as the waste produced during its construction.

TM2 still complies with best practices for environmental sustainability. This is because the majority of the changes to the manuals are administrative. These changes do not affect what is considered best practices in environmental sustainability. The few changes that

are not administrative either are out of the control of Tate Modern or are addressed in finish products. By addressing key aspects of the 2008 manuals, Tate Modern can ensure an environmentally sustainable museum.

Section	2006 Score %	2006 Weight	2008 Weight
Management	76%	15%	12%
Health & Wellbeing	70.50%	15%	15%
Energy & Transport*	78%	25%	
Energy	X	X	19%
Transport	X	X	8%
Water	73%	5%	6%
Materials & Waste**	37.80%	10%	20%
Land Use & Ecology	27.50%	15%	10%
Pollution	64%	15%	10%
Innovation***	X	X	10%
*** Energy and transport are weighted together in the 2006 Bespoke Manual but separately in the 2008 standard.**			
*** Materials and Waste are separate sections in 2008 manual. Materials is 12.5% Waste 7.5%**			
**** Innovation is an extra credit score. 2008 is still based on 100% system but with Innovation it is possible to receive 110%**			

Table 13: Comparison in weighting Schemes

References

BRE Global Ltd. (2009). *BREEAM: The Code for Sustainable Homes* Retrieved June 7, 2010, from http://www.breeam.org/page.jsp?id=86

BRE Global Ltd. (2008). *BREEAM Master Bespoke Manual.* Unpublished manuscript.

Regen SW. (2007). *Policy context - Regen South West* Retrieved June 18, 2010, from http://www.regensw.co.uk/south-west-england/policy-context/

Transport For London. (2006). *Transport Assessment Best Practices.* Retrieved June 16, 2010, from http://www.tfl.gov.uk/assets/downloads/corporate/TAGuidance_LQ.pdf

WORCESTER POLYTECHNIC INSTITUTE

A Comparison of BREEAM 2006 and 2008

Using the Master Bespoke Manual and the Bespoke Manual for Tate Modern

Thaddeus Adams

Robert Cakounes

Alexander Nittel

Kristin Smith

[June 18, 2010]

The table consists of an analysis comparing the Bespoke 2006 BREEAM manual with the 2008 Master Bespoke Manual. The table aims to compare how to achieve each standard and the amount of credits each standard is worth. The key differences column specifies the major differences that arose in the criteria for meeting the standard

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Key

Effect New Weighting System has on the Tate	**Color**
Positive	Green
Negative	Red
Neutral	Grey

Management

Section / Issue Title	Number of Credits Available – Bespoke (BRE Global Ltd, 2006d)	Number of Credits Available – 2008 (BRE Global Ltd, 2010)	Aim of Bespoke (BRE Global Ltd, 2006d)	Aim of 2008 (BRE Global Ltd, 2010)	Notable Differences
Man 1 **Commissioning**	1 Credit- Where evidence provided demonstrates that an appropriate project team member has been appointed to monitor commissioning on behalf of the client to ensure commissioning will be carried out in line with current Building Regulations and (where applicable) best practice. 1 Credit- First the first Credit must be achieved. Where evidence provided demonstrates that seasonal commissioning will be carried out during the first year of occupation, post-construction (or post-fit-out).	1 Credit- An appropriate project team is appointed to deal with the programme's commissioning. Commissioning to be carried out in line with current Building Regulations and BSRIA1 and CIBSE2 guidelines, where applicable. The main contractor accounts for the commissioning programme, responsibilities and criteria within the main programme of works. Specialist commissioning manager is appointed for complex systems, i.e. air conditioning, mechanical ventilation, building management system, ext. Where BMS specified, the commissioning procedures found on page 43 of BREEAM Industrial 2008 must be carried out. All cold storage room must follow criteria also addressed on this page 2 Credits. The Primary credit must be achieved. With that the climate controls need to be tested over a minimum of a 12 month period once the building becomes occupied. Testing all systems under full loads and extremes. **Minimum Standard**	To recognise and encourage an appropriate level of building services commissioning that is carried out in a co-ordinated and comprehensive manner, thus ensuring optimum performance under actual occupancy conditions.	To recognise and encourage an appropriate level of building services commissioning that is carried out in a coordinated and comprehensive manner, thus ensuring optimum performance under actual occupancy conditions.	2008 puts increased requirements for building management system.

Man 2 **Considerate Constructors**	1 credit for a commitment to achieve CCS between 24 and 31.5 2 credits for a commitment to achieve CCS between 32 and 40	1 credit for a commitment to achieve CCS between 24 and 31.5 2 credits for a commitment to achieve CCS between 32 and 40- minimum standard **Exemplary level available if CCS is above 36** **Minimum Standard**	To recognise and encourage construction sites which are managed in an environmentally and socially considerate and accountable manner.	To recognise and encourage construction sites which are managed in an zenvironmentally and socially considerate and accountable manner.	
Man 3 **Construction site impacts**	1 credit- evidence provided demonstrates that 2 or more items a-g are achieved 2 credits- 4 or more items a-g are achieved 3 credits- 6 or more items a-g are achieved (list of a-g criteria in 'Bespoke' 2006 standards page 13) *1 credit- evidence provided demonstrates that all site timber is responsibly sourced*	1 credit- evidence provided demonstrates that 2 or more items a-g are achieved 2 credits- 4 or more items a-g are achieved 3 credits- 6 or more items a-g are achieved (list of a-g criteria in BREEAM Industrial 2008 page 49) *1 credit- evidence demonstrating that 80% of site timber is responsibly sourced and 100% legally sourced*	To recognise and encourage construction sites managed in an environmentally sound manner in terms of resource use, energy consumption, waste management and pollution.	To recognise and encourage construction sites managed in an environmentally sound manner in terms of resource use, energy consumption and pollution.	The criteria list for 2006 includes: 1. Monitor construction waste on site; 2. Sort and recycle construction waste The criteria list for 2008 includes: 1. Main contractor has an environmental materials policy, used for sourcing of construction materials to be utilized on site; 2. Main contractor operates an Environmental Management System 2008- Construction timber 1. 80% responsibly sourced 2. 100% legally sourced 2006- Construction timber 1. 100% responsibly sourced
Man 4 **Building User Guide**	1 credit- Where evidence provided demonstrates the provision of a simple guide that covers information relevant to the tenant/occupants and non-technical building manager on the operation and environmental performance of the	1 credit- 1. Create a Building User Guide that complies with the structure set up in the additional guidance section (BREEAM industrial 2008 page 53) 2. A guide that is relevant to the non-technical building users and appropriate to the stakeholders that occupy the building	To recognise and encourage the provision of guidance to enable a building user to understand and operate the building efficiently, in line with current good practice and	To recognise and encourage the provision of guidance for the non technical building user so they can understand and operate the building efficiently.	

	building. User Guide is on page 25 of 'Bespoke' manual.	**Minimum Standard**	in the manner envisioned by the design team.	
Man 5 **Consultation**	1 Credit- Where evidence provided demonstrates that consultation has been, or is being, undertaken and feedback given to the local community and building users. In addition, advice should also have been sought from any relevant national and local history, archaeological bodies or military history groups regarding the heritage value of the building/site/surroundings 2 Credits- in addition to the above, evidence provided demonstrates that changes to the design and/or action has been taken as a result of the above consultation process. This should include the protection of any parts of the building (or site) having historic or heritage value in accordance with independent advice from English Heritage or a relevant local heritage body.	1 Credit- 1. During Preparation of the brief the categories on page 57 of BREEAM Education 2008 must be followed. 2. Consultation must at least include the issues addressed on page 57 of BREEAM Education 2008. 3. Feedback must be given to the consultation group and include the information on page 57 of BREEAM Education 2008. 2 Credits- 1. All criteria for 1 credit must be addressed. 2 The consultation process method must use an independent 3rd party.	To involve the local community and building users (including business, residents and local government) in contributing towards the design process through consultation in order to increase local "ownership."	To involve the relevant stakeholders (including building users, business, residents and local government) in the design process in order to provide buildings fit for purpose and to increase local "ownership".
Man 6 **Publication of**	1 credit- Where evidence provided demonstrates that the	1 credit- The information found on page 63 of the BREEAM Education 2008 standard must	To recognise and encourage the publication of	To recognise and encourage the publication of

building information	design team are committed to publicizing information about the new development via the internet, newsletters, site visits, presentations, etc.	be publicized on: Developer's website, publicly available literature or press release; Industry/sector or Government/Local Authority sponsored website or information portals; Relevant public sector, organization or institutional website or literature **Minimum standard**	information related to the aspects of the design and procurement process' which reduce the overall environmental impact of the building.	information related to the aspects of the design and procurement process' which reduce the overall environmental impact of the building.	
Man 7 **The development as a learning resource**	1 credit- Where evidence provided demonstrates that the proposed *building* **and/or** *landscape* design provides a learning resource that can be used to facilitate development of environmental issues for students and visitors.	1 credit- 1. At least one credit must be achieved under the Consultation section 2. Subjective requirement but in some way the building must be able to educate the public on environmental awareness. See page 67 of BREEAM Education for list of suggestions. **Minimum stanard**	To recognise and encourage the utilisation of the building structure and site as a learning resource to demonstrate environmental awareness.	To recognise and encourage the use of the building and site as a learning resource for demonstrating environmental awareness.	2008 includes that at least one credit form the "Consultation" section must be achieved.
Man 8 **Post-construction testing- acoustics**	1 Credit- Where evidence can be provided to demonstrate that post-construction acoustic testing will be carried out. The aim of the testing is to ensure that the acoustic performance of the building is in accordance with the acoustic design specification.	N/A	To recognise and encourage a commitment to ensure that acoustic requirements have been effectively implemented.	N/A	This standard was removed due to the introduction of post-construction testing throughout the 2008 manual. The standard is now found as the post-construction regulations for Health and Wellbeing section "Acoustic Performance"

Health and Wellbeing

Section / Issue Title	**Number of Credits Available – Bespoke** (BRE Global Ltd, 2006b)	**Number of Credits Availabl e – 2008** (BRE Global Ltd, 2010)	**Aim of Bespoke** (BRE Global Ltd, 2006b)	**Aim of 2008** (BRE Global Ltd, 2010)	**Notable Differences**
Hea 1 Daylighting	1	1	To improve the level of daylighting for building users. **Exemplary Criteria**	To give building users sufficient access to daylight.	
Hea 2 View Out	1	1	To allow occupants to re-focus their eyes from close work and so reduce the risk of eye-strain.	To allow occupants to refocus their eyes from close work and enjoy an external view, thus reducing the risk of eyestrain and breaking the monotony of the indoor environment.	Requires that at least 20% of wall space is an opening or window. (2008)
Hea 3 Glare Control	1	1	Where evidence provided demonstrates that an occupant controlled glare control system (e.g. internal or external blinds) is fitted to all areas where computer workstations will be located or close work will be undertaken.	To reduce problems associated with glare in occupied areas through the provision of adequate controls.	
Hea 4 High Frequency Lighting	1	1	To reduce the risk of health problems related to frequency of fluorescent lighting. **Minimum Standard**	To reduce the risk of health problems related to the flicker of fluorescent lighting.	All spaced must use high frequency lighting. (2008) Corridors and stairwells do not need to use high frequency lighting. (2006)
Hea 5 Internal and External Lighting Levels	1	1	To ensure lighting has been designed in line with best practice for suitability and visual	To ensure lighting has been designed in line with best practice for visual performance and	

			comfort	comfort.	
Hea 7 Lighting Controls(2006) Lighting Zones(2006) Lighting Zones and Controls (2008)	Lighting Controls-1 Lighting Zones-1	1	Lighting Zones—To optimise the level of occupant control over lighting within each workspace. Lighting Controls—To recognise and encourage where lighting controls allow lighting settings to be quickly and easily adjusted and to optimise the level of lighting control available to building occupants.	Lighting Zones and Controls- To ensure occupants have easy and accessible control over lighting within each *relevant building area*	Lighting Controls and Lighting Zones is one section in 2008 but is two in 2006. It is now only possible to get one credit when two there used to be possible.
Hea 8 Potential for Natural Ventilation	1	1	To ensure adequate cross flow of air in naturally ventilated buildings and future adaptation to natural ventilation in air-conditioned/mechanically ventilated buildings.	To recognise and encourage adequate cross flow of air in naturally ventilated buildings and flexibility in air-conditioned/mechanically ventilated buildings for future conversion to a natural ventilation strategy.	Requires that all occupied spaces have a minimum of two user controls on the supply of fresh-air. (2008)
Hea 9 **2008 Section 8** Internal Air Pollution	1	N/A	To reduce the risk to health associated with poor indoor air quality.	N/A	This section does not appear in the 2008 standards. Although the criteria that is in 2006 the standard appears in the "Indoor Air Quality" standard of the 2008 manual.
Hea 11 Indoor Air Quality	1	1	Where evidence provided demonstrates CO2 levels are monitored and can be regulated in areas with unpredictable occupancy patterns.	To reduce the risk to health associated with poor indoor air quality.	This section includes the criterion for the "Internal Air Pollution" and Ventilation Rates" standards as well as the previous "Indoor Air Quality" standard

Hea 12 Ventilation Rates	1	N/A	To recognise the provision of adequate fresh air rates, in order to maintain a healthy indoor environment.	N/A	The criterion for this standard was moved to "Indoor Air Quality" standard.
Hea 13 Thermal Comfort	1	1	To encourage the use of design tools to ensure that thermal comfort is achieved.	To ensure, with the use of design tools, that appropriate thermal comfort levels are achieved.	
Hea 14 **Section 11 in 2008** Thermal Zoning	1	1	To recognise the provision of controls allowing independent adjustment of heating/cooling systems to reflect differing load requirements.	To recognise and encourage the provision of user controls which allow independent adjustment of heating/cooling systems within the building.	
Hea 15 **Section 12 in 2008** Microbial Contamination	1	1	To ensure the building services are designed and maintained to avoid risk of legionellosis. **Minimum Standard**	To ensure the building services are designed to reduce the risk of legionellosis in operation.	
Hea 16 **Section 13 in 2008** Acoustic Performance	2	2	To ensure the acoustic performance of the building meets the appropriate standards for its purpose	To ensure the acoustic performance of the building meets the appropriate standards for its purpose.	

Energy

Section / Issue Title	**Number of Credits Available – Bespoke** (BRE Global Ltd, 2006a)	**Number of Credits Available – 2008** (BRE Global Ltd, 2010)	**Aim of Bespoke** (BRE Global Ltd, 2006a)	**Aim of 2008** (BRE Global Ltd, 2010)	**Notable Differences**
Ene 1 Reduction of CO2 Emissions	15	15 **Minimum Standard Exemplary Criteria**	To recognise and encourage buildings that are designed to minimise the CO2 emissions associated with their operational energy consumption.	To recognise and encourage buildings that are designed to minimise the CO2 emissions associated with their operational energy consumption.	Based on the percent improvement on benchmarks established by Building Regulations (2006) For new buildings to achieve this credit, construct a comprehensive computer model. From here the building's CO_2 emissions in predicted and is compared directly to a benchmark (2008)
Ene 2 Sub metering of Substantial Energy Uses	1	1 **Minimum Standard**	To recognise and encourage the provision of energy sub-metering to facilitate monitoring of energy use.	To recognise and encourage the installation of energy sub-metering that facilitates the monitoring of in-use energy consumption.	added Domestic Hot Water (2008) All sub-meters must have pulsed output.
Ene 3 Sub-metering of High Energy Load and Tenancy Areas	1	1	To recognise and encourage the provision of energy sub-metering to facilitate energy monitoring by tenant or end-user.	To recognise and encourage the installation of energy sub-metering that facilitates the monitoring of inuse energy consumption by tenant or end user.	

Ene 4 External Lighting	1	1	To recognise and encourage the specification of energy efficient light fittings for external areas.	To recognise and encourage the specification of energy-efficient light fittings for external areas of the development.	80% have efficacy over 100 lamp lumens (2006) The 2008 manual is more specific and detailed than the 2006 manual. This includes the use of different efficiency lights in different areas. I.e. the use of 50 lamp lumens/ circuit Watt with color rendering greater than or equal to 60 for external lighting for building, access ways, and pathways. The lights in car parking lots, associated roads and floodlighting the efficiency of 70 lamp lumens/ circuit Watt and color rendering greater than or equal to 60. (2008) A full list of regulations is on page 108 of the 2008 BREEAM Industrial Manual.
Ene 5 Low or Zero Carbon Technologies	N/A	3-**Minimum standard Exemplary Criteria**	N/A	To reduce carbon emissions and atmospheric pollution by encouraging local energy generation from renewable sources to supply a significant proportion of the energy demand.	This standard exists as "Renewable & low emission energy" in the Pollution section. Introduces an optional way of achieving the first credit. This way is that the organization had a contract with an energy supplier to provide electricity from a 100% renewable energy source
Ene 6 Building fabric performance and avoidance of air infiltration	N/A	1	N/A	To recognise and encourage measures taken to minimise heat loss and air infiltration through the building fabric.	does not exist in 2006 Bespoke installation of personnel doors between internal and external areas within proximity of any adjacent openings for goods delivery specified external goods doors/vehicle delivery bays bay doors travel at 1m/s or take less than 5 sec to close
Ene 7 Lifts	N/A	2	N/A	To recognise and encourage the specification of energy-efficient transportation systems	Does not exist in 2006 Bespoke
Ene 8 Escalators and travelling walkways	N/A	1	N/A	To recognise and encourage the specification of energy-efficient transportation systems.	Does not exist in 2006 Bespoke

Transport

Section / Issue Title	Number of Credits Available – Bespoke (BRE Global Ltd, 2006g)	Number of Credits Available – 2008 (BRE Global Ltd, 2010)	Aim of Bespoke (BRE Global Ltd, 2006g)	Aim of 2008 (BRE Global Ltd, 2010)	Notable Differences
Tra 1 **Provision of Public Transport**	5	5	To recognise and encourage the selection of sites served by good public transport facilities.	To recognise and encourage development in proximity to good public transport networks, thereby helping to reduce transport-related emissions and traffic congestion.	2008 has an 'accessibility index' versus a 'frequency table' in Bespoke.
Tra 2 **Proximity to amenities (2008)/Proximity to Key Amenities (2006)**	1 – if within 500m of post box or grocery shop	1 - if within 500m of the following amenities: a. Grocery shop and/or food outlet b. Post box c. Cash machine	To encourage buildings to be situated within the proximity of key amenities and reduce the need for extended travel.	To encourage and reward a building that is located in proximity to local amenities, thereby reducing the need for extended travel or multiple trips.	
Tra 4 **Proximity to Other Amenities**	1 – if within 1000m of at least 5 of the following amenities: a. Postal facility b. Grocery shop (only qualifies where more than 500m from the site) c. Bank/cash point d. Pharmacy	N/A	To encourage buildings to be situated within the proximity of other amenities and reduce the need for extended travel.	N/A	Does not exist in 2008 Master Bespoke

	e. Doctors surgery/medical centre f. Community centre g. Leisure centre h. Open access public place i. Place of worship j. Public house			
Tra 5 **Cyclist Facilities**	1 - Where evidence is provided to demonstrate that there is adequate provision of covered, secure and well lit cycle racks storage provided for staff & visitors. 1- Where, in addition to the above, information is provided to demonstrate that there is adequate provision of washing and changing facilities available for staff use.	1 - The number of *compliant cycle storage spaces* provided is as follows: a. 10% of *building users* up to 500 **PLUS** b. 7% for *building users* in the range of 501 – 1000 **PLUS** c. 5% for *building users* over 1000 1 – A. The first credit must be achieved. B. At least two of the following *compliant facilities* must be provided for the *building users*: a. Compliant showers b. Compliant changing facilities and lockers for clothes c. Compliant drying space for wet clothes	To encourage building occupants to cycle by ensuring adequate cyclist facilities are or will be present on site.	To encourage buildings to be situated within the proximity of other amenities and reduce the need for extended travel.

Pedestrian and Cyclist Safety	1	1	Where evidence provided demonstrates that the site layout has been designed to minimise risks to pedestrians and cyclists.	To recognise and encourage the provision of safe and secure pedestrian and cycle access routes on the development.	2008 regulations three possible regulation for cycle and pedestrian paths: 1. Pedestrian and cycle paths are shared- a. minimum of 3.0m path 2. Cycle lane spate: a. Cycle path; minimum 2.0 m b. Pedestrian path minimum 1.5 m 3. Cycle path is part of carriageway: a. Minimum with is 1.5m 2006 states that cycle lane can form part of the carriageway but cannot be combined with the pedestrian walk way. 1. Cycle lanes minimum of 1.0m 2. Two way cycle lane minimum 1.8m 3. Pedestrian walk way minimum of 1.2m
Travel Plan	1 - Where evidence is provided to demonstrate that a travel plan has been developed and tailored to the specific needs of the users of the assessed development.	1 – See Assessment Criteria page 139	To recognise the consideration given to accommodating a range of travel options for building users, thereby encouraging the reduction of user reliance on forms of travel that have the highest environmental impact.	To recognise the consideration given to accommodating a range of travel options for building users, thereby encouraging the reduction of user reliance on forms of travel that have the highest environmental impact.	Increase criteria in most sections of the standards in 2008
Maximum Car Parking Capacity	2 - Where evidence is provided to demonstrate	2 - **First credit** 1. No more than	To encourage the use of other means of transport	To encourage the use of alternative	

	that the number of parking spaces provided for the building has been limited. First credit: 1. Only 1 parking space is provided for every 3 building users. Second credit: 1. Only 1 parking space is provided for every 4 building users.	one parking space is provided for every three *building users*. **Second credit** 1. No more than one parking space is provided for every four *building users*.	to the building other than the private car.	means of transport to the building other than the private car, thereby helping to reduce transport related emissions and traffic congestion.
Travel Information space	1 - Where evidence is provided to demonstrate that there is a dedicated space within the development for the provision of up-to-date public transport information.	1. Provide a dedicated space for the provision of local public transport and taxi information.	To encourage building users/visitors/customers to maximise the use of public transport for travel by providing up-to-date information on local public transport routes and timetables.	To ensure the building has the capacity to provide users with up-to-date information on local public transport routes and timetables.
Deliveries & maneuvering	1 - Where evidence is provided to demonstrate that vehicle access areas have been designed to ensure adequate space for manoeuvring delivery vehicles and provide space for storage of refuse skips and pallets.	1 – no minimum standards – see Assessment Criteria – page 145	To ensure that disruption due to delivery vehicles is minimised through well planned access to the site.	To ensure that safety is maintained and disruption due to delivery vehicles minimised through wellplanned layout and access to the site.

Water

Section / Issue Title	Number of Credits Available – Bespoke (BRE Global Ltd, 2006h)	Number of Credits Available – 2008 (BRE Global Ltd, 2010)	Aim of Bespoke (BRE Global Ltd, 2006h)	Aim of 2008 (BRE Global Ltd, 2010)	Notable Differences
(Wat-1) **Water Consumption**	3	3 **Minimum Standard**	To minimise the consumption of potable water in sanitary applications.	To minimise the consumption of potable water in sanitary applications by encouraging the use of low water use fittings	
(Wat-2) **Water Meter**	1	1 **Exemplary criteria** **Minimum Standard**	To ensure water consumption can be monitored and managed and therefore encourage reductions in water consumption.		2008 includes "For developments with multiple units, a pulsed water meter is specified on the supply to each separate unit."
(Wat-3) **Major Leak Detection**	1	1	To reduce the impact of major water leaks	To reduce the impact of major water leaks that may otherwise go undetected	
(Wat-4) **Sanitary Supply Shut Off**	1	1	To reduce risk of minor leaks in toilet areas	To reduce risk of minor leaks in toilet facilities	
(Wat-5) **Water Recycling**	1	1	To encourage the collection and use of waste water or rainwater to meet toilet flushing needs and reduce the demand for potable fresh water.	To encourage the collection and re-use of waste water or rainwater to meet toilet flushing needs and reduce the demand for potable fresh water.	

(Wat-6) **Water Irrigation**	1	1	To reduce the consumption of potable water for plant and landscape irrigation	To reduce the consumption of potable water for ornamental planting and landscape irrigation.

Waste / Materials

Section / Issue Title	Number of Credits Available – Bespoke (BRE Global Ltd, 2006e)	Number of Credits Available – 2008 (BRE Global Ltd, 2010)	Aim of Bespoke (BRE Global Ltd, 2006e)	Aim of 2008 (BRE Global Ltd, 2010)	Notable Differences
Materials specification – Major building elements	7 - Where evidence provided demonstrates that the major building elements specified have an 'A rating', as defined in the *Green Guide to Specification*.	6 Provide evidence that materials used are rated by the "Green Guide." Points are awarded based on rating given in the "Green Guides"	To recognise and encourage the use of construction materials with a low environmental impact over the full life cycle of the building.	To recognise and encourage the use of construction materials with a low environmental impact over the full life cycle of the building.	
Hard landscaping & boundary protection	1 - Where at least 80% of the combined area of external hard landscaping and boundary protection specifications achieve an A rating, as defined by the Green Guide to Specification.	1 - Where at least 80% of all external hard landscaping and boundary protection (by area) achieves an A or A+ rating, as defined in the *Green Guide to Specification* www.thegreenguide.org.uk	To recognise and encourage the specification of materials for boundary protection and external hard surfaces that have a low environmental impact, taking account of the full life cycle of materials used.	To recognise and encourage the specification of materials for boundary protection and external hard surfaces that have a low environmental impact, taking account of the full life cycle of materials used.	
Re-Use of Facade	1 - Where at least 50% of the total façade (by area) is re-used and at least 80% of there-used façde (by mass) comprises in-situ re-used material.	1 a. At least 50% of the total final building façade (by area) is reused. b. At least 80% of the reused façade (by mass) comprises in-situ reused material.	To recognise and encourage the re-use of existing façades from buildings that occupy the site.	To recognise and encourage the in-situ reuse of existing building façades.	
Re-Use of (Building)	1 - Where evidence provided demonstrates	1 - A. Where at least 80% by volume of an existing	To recognise and encourage the re-use of	To recognise and encourage the	

Structure	that a design re-uses at least 80% of an existing primary structure and for part refurbishment and part new build, the volume of the re-used structure comprises at least 50% of the final structure's volume.	primary structure is reused without significant strengthening or alteration works. B. Where a project is part refurbishment and part new build, the reused structure comprises at least 50% by volume of the final building, i.e. any new-build extension to a building being refurbished should not be larger than the original building to qualify for this credit.	existing structures that previously occupied the site.	reuse of existing structures that previously occupied the site.
Recycled aggregates	1 - Where significant use of crushed aggregate, crushed masonry or alternative aggregates (manufactured from recycled materials) are specified for 'high grade' aggregate uses (such as the building structure, ground slabs, roads, etc.)	1 - Where the amount of recycled and secondary aggregate specified is over 25% (by weight or volume) of the total *high-grade* aggregate uses for the building. Such aggregates can be **EITHER**: a. Obtained on site **OR** b. Obtained from waste processing site(s) within a 30km radius of the site; the source will be principally from construction, demolition and excavation waste (CD&E) – this includes road plannings **OR** c. Secondary aggregates obtained from a non-construction post-consumer or post-industrial by-product source (see Compliance Notes).	To recognise and encourage the use of recycled aggregates in construction thereby reducing the demand for virgin material.	To recognise and encourage the use of recycled and secondary aggregates in construction, thereby reducing the demand for virgin material.
Responsible Sourcing of	1 - Where materials used in key building	3 (new build/refurbs) 2 (Fit Out)	To recognise and encourage the	To recognise and encourage the

Materials	elements are responsibly sourced.	**Exemplary Criteria**	specification of responsibly sourced materials for key building elements.	specification of responsibly sourced materials for key building elements.
Designing for robustness	1 - Where protection is given to vulnerable parts of the building such as areas exposed to high pedestrian traffic, vehicular and trolley movements.	1. A. Internal and external areas of the building where vehicular, trolley and pedestrian movement occur have been identified. B. Suitable durability and protection measures or design features have been specified to prevent damage to the vulnerable parts of these building areas from such traffic. This must include, but is not necessarily limited to: a. Protection from the effects of high pedestrian traffic in main entrances, public areas and thoroughfares (corridors, lifts, stairs, doors etc). b. Protection against any internal vehicular/trolley movement within 1m of the internal building fabric in storage, delivery, corridor and kitchen areas. c. Protection against, or prevention from, any potential vehicular collision where vehicular parking and manoeuvring occurs within 1m of the external building façade for all car parking areas and within 2m for all delivery areas.	To recognise and encourage the protection of exposed parts of the building and landscaping to avoid the need for frequent replacement.	To recognise and encourage adequate protection of exposed parts of the building and landscape, therefore minimising the frequency of use of replacement materials.
Storage of recyclable waste	1 – Where a central, dedicated storage space is provided for materials that can be	1 - 1. Clearly labeled dedicated storage space. 2. The size of space allotted	To recognise and encourage recycling of consumables in order to reduce the demand for	To recognise the provision of dedicated storage facilities for a

	recycled. This can be either within the building itself, or on site using skips, (provided there is good access for collections and it is within easy reach of the building).	for recyclable materials must be adiquite for all occupants of the building while following criteria found on page 201 of 2008 BREEAM Industrial **Minimum Standard**	virgin material and the amount of waste going to landfill or incineration.	building's operational-related recyclable waste streams, so that such waste is diverted from landfill or incineration.	
Composting	1 - Where evidence provided demonstrates there is either a composting vessel on site for organic waste and adequate storage for organic material OR there is a dedicated space for organic waste to be stored prior to removal and composting at an alternative site.	1- 1. There is a vessel of adequate size to store all organic waste on site 2. Space provided for the separation of food waste and composted organic matter. 3. At least one water outlet provided for cleaning in and around the area. **OR** 1. Where space is not available for composting on site, space must be made available for storage and a system must be set up for temporary storage and transport to a site for further composting.	To encourage the provision of facilities for composting of organic waste, thereby reducing waste from the development going directly to landfill.	To encourage the provision of facilities that help facilitate the reduction in volume of compostable organic waste going directly to landfill during the building's operation.	Addition of water outlet near storage area and regulations for separation of food waste and composted organic matter. (2008)
Insulation	N/A	First credit - Embodied Impact calculated with the insulation index Second credit - Responsible Sourcing: Insulation in the walls, on the ground floor, in the roof, and integrated into building services must be 80% responsibly sourced	N/A	To recognise and encourage the use of thermal insulation which has a low embodied environmental impact relative to its thermal properties and has been responsibly sourced.	Is related to the "Insolant" of the 2006 manual. The 2008 Manual puts more restrictions on this section. To achieve the credit, the building must achieve a grade of "A" in the "Green Guide" for a grad

Construction Site Waste Management	N/A	4 (new build – based o resource efficiency benchmarks/refurb) 2 (Fit Out) • New Build and Major Refurbishments - Up to three credits are available • Fit Out only assessments - one credit is available • New build, Refurbishment and Fit Out only projects - one additional credit is available • One exemplary credit is available – see p. 191-192 **Exemplary criteria**	N/A	To promote resource efficiency via the effective and appropriate management of construction site waste.	Amount of waste generated per $100m^2$ One Credit 1. 13.0-16.6 m^3 2. 6.6-8.5 tonnes Two credtits 1. 9.2-12.9 m^3 2. 4.7-6.5 tonnes Three cridits 1. <9.2 m^3 2. <4.7 tonnes

Land Use and Ecology

Section / Issue Title	Number of Credits Available – Bespoke (BRE Global Ltd, 2006c)	Number of Credits Available – 2008 (BRE Global Ltd, 2010)	Aim of Bespoke (BRE Global Ltd, 2006c)	Aim of 2008 (BRE Global Ltd, 2010)	Notable Differences
Re-use of Land	1 Credit- Where evidence is provided to demonstrate that the footprint of the proposed development largely falls within the boundary of land previously developed. At Least 75% of the proposed footprint is on previously developed in the last 50 years	1 Credit- At least 75% of the proposed development's footprint is on an area of land which has previously been *developed* for use by industrial, commercial or domestic purposes in the last 50 years.	To encourage the re-use of land that has been previously occupied by building developments and discourage the use of previously undeveloped land for building.	To encourage the reuse of land that has been previously developed, and discourage the use of previously undeveloped land for building.	
Contaminated land	1 Credit- Where evidence is provided to demonstrate that the land used for the new development has, prior to development, been defined as contaminated, and where adequate remedial steps have been taken to decontaminate the site prior to construction.	1 Credit- If a site is deemed to be significantly contaminated, the following tasks must be undertaken prior to construction, determining: degree of contamination; the contaminant source/type, the options for remediating sources of pollution which present an unacceptable risk to the site. The client then must confirm that the site will be remediation with accordance to the strategy proposed.	To encourage positive action to use contaminated land that otherwise would not have been developed.	To encourage positive action to use contaminated land that otherwise would not have been remediated and developed.	
Ecological value of land and protection of ecological features	1 Credit- Where evidence is provided to demonstrate that the construction zone is defined as land of low ecological value and all existing features of ecological value will be fully protected from	1 Credit- Ensuring the protection of the ecology of the surrounding area, specific criteria found on page 208 of BREEAM Industrial 2008	To encourage development on land that already has limited value to wildlife and to protect existing ecological features from	To encourage development on land that already has limited value to wildlife and to protect existing ecological features from substantial	

	damage during site preparation and construction works.		substantial damage during site preparation and completion of construction works.	damage during site preparation and completion of construction works.
Mitigating ecological impact	1 Credit- Where evidence is provided to demonstrate the change in ecological value of the site, as a result of development, is between less than zero and equal to, or less than, minus nine species, i.e. a small negative change. 2 Credits- Where evidence is provided to demonstrate there is no negative change in the ecological value of the site as a result of development, i.e. equal to, or greater than, zero species.	1 Credit- where the change in ecological value of the site is less than zero and equal to or greater than minus nine plant species i.e. a minimal change. 2 Credit- where the change in ecological value of the site is equal to or greater than zero plant species i.e. no negative change. **Minimum Standard**	To minimise the impact of a building development on existing site ecology.	To minimise the impact of a building development on existing site ecology.
Enhancing site ecology	1 Credit- Where evidence is provided to demonstrate that the design team (or client) has i) appointed a professional to advise and report on enhancing and protecting the ecological value of the site; and ii) implemented the professional's recommendations for general enhancement and protection for site ecology. 2 Credits- Where	1 Credit- A suitable Qualified ecologist has been appointed to report on enhancing and protecting the ecology of the site, these results are published in an Ecology Report. Also the general recommendations of the Ecology Report must be, or will be, implemented. 2 Credits- First the first credit must be achieved. From there the Ecology Report has been implemented and the ecological value was increased up to (but not including) 6 plant species.	To maintain and enhance the ecological value of the site.	To recognise and encourage actions taken to maintain and enhance the ecological value of the site as a result of development.

	evidence is provided to demonstrate a positive increase in the ecological value of the site of up to (but not including) 6 species. 3 Credits- Where evidence is provided to demonstrate a positive increase in the ecological value of the site of 6 species or greater.	3 Credits- First the first credit is achieved. The Ecological value of the site is than increased by 6 plants species or greater.		
Long term impact of biodiversity	1 Credit- Where evidence is provided to demonstrate that the client has committed to achieving the mandatory requirements listed below and at least two of the additional requirements. 2 Credits- Where evidence is provided to demonstrate that the client has committed to achieving the mandatory requirements listed below and at least four of the additional requirements. Requirements can be found on page 25 of 'Bespoke' Land Use & Ecology manual	1 Credit- Whre there is a commitment to achieve the mandatory criteria and at least two of the additional criteria. 2 Credits- Where there is a commitment to achieve the mandatory critera and at least four of the additional criteria. Critira found on page 277 of BREEAM Industry 2008	To minimise the long term impact of the development on the site's and surrounding area's biodiversity.	To minimise the long term impact of the development on the site's, and surrounding area's biodiversity.

Pollution

Section / Issue Title	Number of Credits Available – Bespoke (BRE Global Ltd, 2006f)	Number of Credits Available – 2008 (BRE Global Ltd, 2010)	Aim of Bespoke (BRE Global Ltd, 2006f)	Aim of 2008 (BRE Global Ltd, 2010)	Notable Differences
(Pol-1) Refrigerant GWP- Building Services	1	1	To reduce the contribution to potential climate change from refrigerants with a high global warming potential.	To reduce the contribution to climate change from refrigerants with a high global warming potential	
(Pol-2) Preventing Refrigerant Leaks	2	2	To reduce the emissions of refrigerants to the atmosphere arising from leakages in cooling plant.		
(Pol-4) Insulant GWP	1	N/A	To reduce the potential for global warming from substances used in the manufacture or composition of insulating materials.	N/A	This criteria is cover in the materials section of the 2008 manual under "Insulation" The 2008 Manual puts more restrictions on this section. To achieve the credit, the building must achieve a grade of "A" in the "Green Guide" for a grad
(Pol-6 [Pol-4 2008]) NOx Emissions From Heating Source	3	3	To encourage the use of heating that minimises NOx emissions, and therefore reduces pollution of the local environment.		
(Pol-7 [5 in 2008]) (Minimising) Flood Risk	3	3	To encourage the development of buildings in areas with reduced risk of flooding and ensure that storm water run-off from the development does not increase the flood risk on site or elsewhere.	To encourage development in low flood risk areas or to take measures to reduce the impact of flooding on buildings in areas with a medium or high risk of flooding	A Flood Risk Assessment must be achieved for all buildings to confirm the level of flood risk to a building.

(Pol-8[6]) Minimising Watercourse Pollution	1	1	To reduce the potential for pollution to natural watercourses from surface water run-off from buildings and hard surfaces.		Criteria deals more with SUDs in 2008 manual and other guidelines rather than specific BREEAM guidelines
(Pol-11) Renewable and Low Energy Emission	3	N/A	To reduce atmospheric pollution by encouraging locally generated renewable or low emission energy to supply a significant proportion of the building's energy demand	N/A	This standard appers as "Low or Zero Carbon Technologies" in the Energy section.
(Pol-12[7]) Reduction of Night-time Light Pollution	1	1	To ensure that night-time lighting is concentrated in the appropriate areas and that upward lighting is minimised, reducing unnecessary, light pollution, energy consumption and nuisance to neighbouring properties		2008 includes "Illuminated advertisements, where specified, must be designed in compliance with ILE Technical Report 5 – *The Brightness of Illuminated Advertisements*"
(Pol-13[8]) Noise Attenuation	1	1	To reduce the likelihood of complaints of noise from the occupants of nearby noise-sensitive buildings, such as homes, hospitals and schools.	To reduce the likelihood of noise from the new development affecting nearby noise-sensitive buildings	
(Pol-14) Kitchen Wastewater Filtration	1	N/A	To prevent wastewater contaminated with liquid vegetable fat and grease being discharged to the sewers, therefore reducing the loading of local sewage treatment facilities.	N/A	N/A

References

BRE Global Ltd. (2006a). *Tate Modern Bespoke BREEAM Manual for Energy.* Unpublished manuscript.

BRE Global Ltd. (2006b). *Tate Modern Bespoke BREEAM Manual for Health and Wellbeing.* Unpublished manuscript.

BRE Global Ltd. (2006c). *Tate Modern Bespoke BREEAM Manual for Land Use and Ecology.* Unpublished manuscript.

BRE Global Ltd. (2006d). *Tate Modern Bespoke BREEAM Manual for Management.* Unpublished manuscript.

BRE Global Ltd. (2006e). *Tate Modern Bespoke BREEAM Manual for Materials and Waste.* Unpublished manuscript.

BRE Global Ltd. (2006f). *Tate Modern Bespoke BREEAM Manual for Pollution.* Unpublished manuscript.

BRE Global Ltd. (2006g). *Tate Modern Bespoke BREEAM Manual for Transport.* Unpublished manuscript.

BRE Global Ltd. (2006h). *Tate Modern Bespoke BREEAM Manual for Water.* Unpublished manuscript.

BRE Global Ltd. (2010). *BREEAM Master Bespoke Manual.* Unpublished manuscript.

WORCESTER POLYTECHNIC INSTITUTE

Analysis of BREEAM

Innovation and Tate Modern

By: Thaddeus Adams

Edited By: Robert Cakounes, Alexander Nittel, Kristin Smith

24 June 2010

This document is an analysis of BREEAM with respect to innovative technologies. This document includes an analysis of 2006 BREEAM standards, the 2008 BREEAM "Innovation" standards, and other institutions that recognise innovation. Tate Modern is used as a case study to support the analyses.

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Section 1: Introduction

Tate Modern will use a rigorous environmental assessment method to ensure that the expansion is environmentally sustainable. The Building Research Establishment (BRE) uses the Building Research Establishment Environmental Assessment Method (BREEAM) to assess newly constructed or renovated buildings. BREEAM has recently gained popularity as a robust environmental assessment method. There have been comparisons between BREEAM and the renowned assessment method implemented by US Green Building Council (USGBC), known as Leadership in Energy and Environmental Design (LEED). The advantages of BREEAM will be determined throughout this report.

Although BREEAM is regarded as robust assessment method, it does have limitations. Concerns with BREEAM revolve around the "tick box" mentality behind the method Applicants would use BREEAM to gain minimal accreditation rather than to guide their building towards sustainability. The "tick box" mentality limits what BREEAM recognizes concerning environmental sustainability, particularly with innovative technologies. BREEAM will be analysed throughout this report to determine if these limitations are an actuality. This report will also analyse how BREEAM addresses its limitations with regard to innovation. This report contains an analysis of LEED standards as an example of another environmental assessment method that addresses the limitations found in BREEAM.

Tate Modern should gain recognition for the innovative technologies that it will implement in its expansion. For a definition of innovation, refer to the section **Why the Technologies Are Innovative**. The recycled waste heating system, borehole cooling system, and desiccant dehumidification system of Tate Modern are the innovative technologies that are detailed in this report. This report also details why they are innovative. These technologies, and the assessment of Tate Modern by BREEAM, offer an opportunity to analyse BREEAM standards with respect to innovative technologies. In the case that BREEAM does not offer recognition for these innovative technologies, this report will give examples of institutions that would recognise Tate Modern's innovations..

This report has three purposes. They are to:

- Determine the strengths and weaknesses of BREEAM with relation to innovation;

-Determine how BREEAM has evolved with regards to recognizing innovation; and

-Determine methods to gain recognition for innovation.

Tate Modern will be used as a case study to conduct the analyses.

Section 2: Innovative Technologies at Tate Modern

2.1 Recycled Waste Heating System

The recycled waste heat system is a simple process. In order to cool down the neighbouring transformers, EDFE runs water through the system. The water absorbs the heat emitted then leaves the transformers. This process is a common practice for the cooling of transformers.. Tate Modern will use the warm water for heating purposes.

The recycled waste heating system is an effective and environmentally sustainable alternative to traditional heating systems. The waste heat that the transformers emit can be recycled to provide at least 65% of Tate Modern's low-grade heat requirements (Max Fordham Consulting Engineers, 2009). This reduces the need for other heating sources that release harmful emissions, such as gas-fired furnaces.. The recycled waste heat system releases virtually no emissions. This is because the process only requires energy to pump water throughout Tate Modern.

2.2 Borehole Cooling System

The borehole cooling system is a simple process. It uses the consistent cool temperatures of groundwater to cool the building. The process involves drilling boreholes into the ground. Typically, boreholes are 70 metres deep in London to reach clean water. However, Tate Modern needs to drill only 10 metres deep to reach clean water (Max Fordham Consulting Engineers, 2009). Pumps draw water up into the building. The water runs through the building. Tate Modern then pumps it through a different borehole back underground.

The borehole cooling system is an efficient substitute for traditional cooling processes. It supplies at least 97% of the required low grade cooling for Tate Modern(Max Fordham Consulting Engineers, 2009). Traditional cooling systems contain compounds that are harmful to the environment. The borehole cooling system does not use harmful refrigerants. Refrigerants demand high amounts of energy to operate. The borehole cooling system only demands energy to pump water. The efficiency coefficients of conventional air conditioners and the borehole cooling system are 2 and 20 respectively (Max Fordham Consulting Engineers, 2009). This means that the borehole cooling system is ten times more efficient than air conditioners.

2.3 Desiccant Dehumidification System

Typical museum dehumidification systems are energy intensive. This is due to the extreme cooling and heating required. A conventional dehumidification system cools intake air to the dew point. Once the humidity is condensed out of the air, it is reheated to a comfortable temperature.

The desiccant dehumidification system does not involve as much heating or cooling as a typical dehumidification system. Desiccant dehumidification involves a surface that easily absorbs water. This surface is the desiccant. This desiccant is formed into a wheel that spins between two compartments, one the intake and the other the outlet. Water attaches to the desiccant surface in the intake compartment. The desiccant spins into the other compartment, which is heated. This evaporates the water. However, this also heats the desiccant wheel. This in turn heats the air in the intake. The intake air is then cooled before being used in the building. Figure 1.1 shows the desiccant dehumidification process.

The desiccant dehumidification system is dependent on the borehole cooling and recycled waste heat systems. Normally, a desiccant dehumidifier is less efficient than conventional dehumidification processes. Due to the use of the borehole cooling and recycled waste heating systems however, this process is now more effective. The minimal emissions of the heating and cooling systems and the implementation of desiccant dehumidification system produce less CO_2 and use less energy than typical museum dehumidification systems.

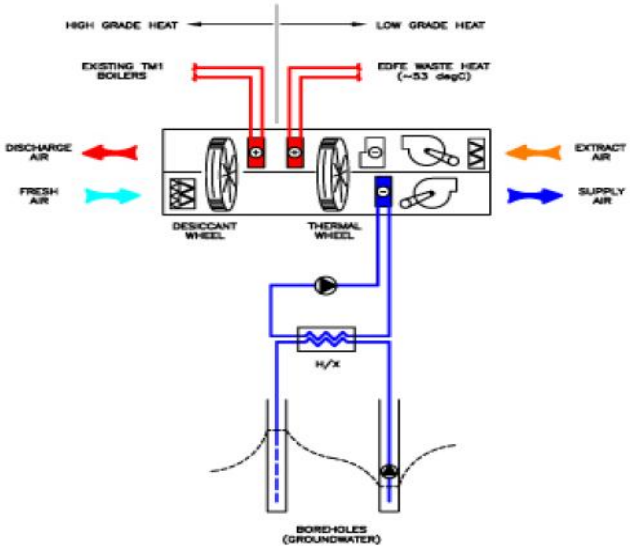

Figure 1.1 (Max Fordham Consulting Engineers, 2009)

2.4 Why the Technologies Are Innovative

Innovation is a broad term that can encompass different aspects of technologies and processes. For the purpose of this report, 'innovative technologies" refers to systems that are alternatives to traditional practices. The alternative is implemented because the site condition allows it to be more efficient than the conventional technology. Project teams must use creative thinking in order to determine where and how they can implement innovative technologies.

The recycled waste heat system meets the criteria of an innovative technology. The system is a site-specific opportunity due to the neighbouring transformer. In addition, the system is an alternative to traditional heating devices, such as gas-fired furnaces. Lastly, the system reduces the energy demand and emissions for Tate Modern. This is the first time a building uses recycle waste heat from a transformer.

The borehole cooling system also meets the criteria for innovative technologies. The borehole cooling system is an alternative to less efficient and potentially harmful refrigerants. Borehole cooling is not a new practice. However, the creative thinking of the project team allowed for innovation. Tate Modern is on the south side of the Thames where clean water is just 10 meters below ground (Max Fordham Consulting Engineers, 2009). The engineers recognized an opportunity to save on cost and energy by only pumping from 10 metres deep instead of 70 metres (Max Fordham Consulting Engineers, 2009).

The desiccant dehumidification system meets the criteria of innovative technology. The desiccant dehumidification system is a site-specific and creative process. It relies on two other site-specific systems, the borehole cooling and recycled waste heating system. The desiccant dehumidification system is only a more efficient alternative to conventional systems because of the use of the other two systems. Without these systems, the cost and process of its instillation would outweigh the benefits that the desiccant dehumidification system offers (Max Fordham Consulting Engineers, 2009).

Section 3: Analysis of BREEAM With Relation To Innovation

3.1 Analysis of 2006 Tate Modern Bespoke Manual

The BREEAM manual used to assess Tate Modern is a 2006 bespoke, or custom, manual. This is because Tate Modern does not qualify for existing BREEAM manuals such as BREEAM offices, education, or retail. Specific sections in this manual are "Management", "Health and Wellbeing", "Energy", "Transport", "Water", "Materials and Waste", "Land Use and Ecology", and "Pollution." This part of the report is an analysis of the 2006 BREEAM manual. This analysis determines which sections offer opportunity to recognize the innovative technologies at Tate Modern.

It is difficult for the "Management" section to reflect innovative processes and designs. A majority of the "Management" section encompasses the pre-construction and design phases of the project. An example of a standard that is typical to this section is the "Commissioning" standard. The aim of this standard is "To recognise and encourage an appropriate level of building services commissioning that is carried out in a co-ordinate and comprehensive manner, thus ensuring optimum performance under actual occupancy conditions. (BRE Global Ltd, 2006c). This aim does not relate to the innovative technologies at Tate Modern.

The "Health and Wellbeing" section does not offer opportunity to recognize environmental sustainability. The "Health and Wellbeing" section encompasses attributes of the building that add to the health and safety of the inhabitants. An example of a typical standard in this section is the "High Frequency Lighting" standard. The aim of this standard is "to reduce the risk of health problems related to frequency of fluorescent lighting" (BRE Global Ltd, 2006a). This aim is not relevant to the innovative features at Tate Modern.

Future revisions to the "Energy" section could offer opportunity to reflect on the innovative technologies at Tate Modern. However, the 2006 manual does not offer this opportunity. The "Energy" section encompasses energy use and CO_2 emissions. BRE bases the credits awarded in this section on results. The criteria do not consider *how* applicants achieve the result. If the standards were to reflect how technologies reduce energy use and carbon dioxide emissions, then the innovative technologies at Tate Modern would be recognised.

The "Transport" section does not offer opportunity to recognize environmental sustainability. The "Transport" section encompasses accessibility to the museum. An example of a typical standard in this section is the "Provisions of Public Transport" standard. The aim of this

standard is “to recognise and encourage the selection of sites served by good public transport facilities” (BRE Global Ltd, 2006e). This aim is not relevant to the innovative features at Tate Modern.

The “Water” section offers little opportunity to recognize environmental sustainability. The “Water” section encompasses water use and water waste. An example of a typical standard in this section is the “Water Recycling” standard. The aim of this standard is “to encourage the collection and use of wastewater or rainwater to meet toilet flushing needs and reduce the demand for portable freshwater” (BRE Global Ltd, 2006f). This aim is not relevant to the innovative features at Tate Modern. BREEAM does not recognize the way Tate Modern uses water in its innovation. There is possibility for future manuals to include standards for innovative processes using water.

The “Materials and Waste” section does not offer opportunity to recognize environmental sustainability. The “Waste and Materials” section encompasses the use of environmentally sustainable materials and minimising unnecessary waste during the construction phase. An example of a typical standard in this section is the “Composting” standard. The aim of this standard is “to encourage the provision of facilities for composting of organic waste thereby reducing waste from the development going directly to landfills” (BRE Global Ltd, 2006d). This aim is not relevant to the innovative features at Tate Modern.

The “Land Use and Ecology” section does not offer opportunity to recognize environmental sustainability. The “Land Use and Ecology” section encompasses standards pertaining to the area around the building. An example of a typical standard in this section is the “Mitigating Ecological Impact” standard. The aim of this standard is “to maintain and enhance the ecological value of the site” (BRE Global Ltd, 2006b). This aim is not relevant to the innovative features at Tate Modern.

Future revisions to the “Pollution” section could offer opportunity to reflect on the innovative technologies at Tate Modern. However, the 2006 manual does not offer this opportunity. The “Pollution” section encompasses NO_x emissions and refrigerants. Tate Modern’s innovative processes reduce NO_x emissions to virtually zero. This is enough to gain credit from BREEAM, but does not reflect *how* Tate Modern achieves the credits. Similarly, BREEAM recognises that there are no environmentally harmful refrigerants but does not offer recognition for *how* this standard is accomplished. If the standards were to reflect how technologies lower the

emissions or how the technologies reduce the need for unsustainable practices such as refrigerants, the innovative technologies at Tate modern would be recognised.

In conclusion, the 2006 manual does not recognise innovation. However, there are newer BREEAM standards. The 2008 BREEAM manuals introduce an "Innovation" section. The next section of this report, **Analysis of 2008 BREEAM "Innovation" Standard,** contains further details about innovation credits.

3.2 Analysis of 2008 BREEAM 'Innovation' Standard

BREEAM applicants rarely apply for innovation credits because the process is tedious. First of all, the application process costs £1000. The applicant must fill out an application form. This application must include a report that specifies what is innovative about the building and why it is innovative. If BRE decides that the processes or technologies are innovative, BRE awards the innovation credit and exemplary credits. BREEAM Assessor 1 says that this process is unfair to the applicants because the application process is tedious, time consuming, and the onus is on the applicants to prove innovation with vague BREEAM guidelines. BREEAM Assessor 1 only knows of one applicant that considered applying for innovation credits. BREEAM Assessor 1 also describes BREEAM as a "cumbersome" process, so dealing with innovation credits in addition to the normal assessment process seems too overwhelming.

If BRE revises the process, gaining credit for innovation will be less deterring and more applicants will apply for innovation credits. There are several ways BRE can solve the problems with innovation credits. Implementing site-specific and innovation standards throughout the other sections seems like a logical next step for BREEAM standards. This would eliminate the need for an independent application process to gain credit for innovation. Mimicking other environmental assessment methods, such as LEED and HQE, on site-specific innovation is a way to implement innovation credits throughout core sections such as "Energy." BREEAM Assessor 1 said he would not be surprised if those were the steps that BREEAM took. The BREEAM standards are already a collaboration of government regulations or other established institutions, so implementing LEED or HQE criteria is within the nature of BRE. An analysis of LEED standards is in the section, **Institutions that Recognize Innovation.**

Section 4: Institutions That Recognise Innovation

4.1 Analysis of 2009 LEED New Construction And Major Renovation

This section of the report stresses how Leadership in Energy and Environmental Design (LEED) acknowledges innovation using Tate Modern as an example. This establishes strengths and limitations relative to BREEAM. Note that this is a hypothetical situation. This is a look into if Tate Modern were to use LEED standards. Tate Modern ***IS NOT*** going to be assessed using LEED standards.

The table below lists credits that the innovative processes could possibly address. Readers can find clarification of the table in the text following it.

TABLE 1: ANALYSIS OF LEED STANDARDS

This section is an analysis of "LEED 2009 for New Construction and Major Renovations" manual (LEED, 2009)

Standard	Relevance of Technologies	Technologies Involved	How Technologies Relate
Innovation in Design (ID 1)	Very High	-Heating -Cooling -Dehumidification	Tate Modern achieves the credit by explaining how innovative processes help to achieve other standards, or explaining how they help reduce environmental impact.
Minimum Energy Performance (EAP 2)	High	-Heating -Cooling -Dehumidification	All three technologies lower energy usage, making the credit easier to obtain.
Optimized Energy Performance (EA 1)	High	-Heating -Cooling -Dehumidification	All three technologies lower energy use, making the credit easier to obtain.
Thermal Comfort-Design (IEQ 7.1)	High	-Heating -Cooling	Tate Modern uses recycled waste heat and borehole cooling systems to control the temperature level.
Enhanced Refrigerant Management (EA 4)	Medium	-Cooling	Borehole cooling reduces the need for refrigerants.
Thermal Comfort Verification (IEQ 7.2)	Low	-Heating -Cooling	The heating and cooling systems deal with temperature control, but do not deal with verification of temperature levels.
Site Selection (SS 1)	Low	-Heating	The use of the neighbouring transformers reduces the need to build new structure for heating. The link to innovative technology may be a stretch.
On-Site Renewable Energy (EA 2)	Very Low	-Heating -Cooling	Although the credit seems to refer to electricity, the heating and cooling systems recycle the water to the point where it is a zero sum consumption after it is recycled, fitting the definition of a renewable resource.

The **Innovation in Design** credit is highly relevant because the technologies that Tate Modern recognition for would all gain points in a LEED assessment from this standard. The relationship between the technologies and the criteria is very clear.

The **Minimum Energy Performance** credit is highly relevant to the recycled waste heating system, borehole cooling system, and desiccant dehumidification system because those three systems are directly responsible for decreased energy use in Tate Modern. Although there are other methods Tate Modern would implore to achieve this credit, those three technologies directly affect the outcome of points earned. LEED recognises how Tate Modern achieves the lower energy use.

The **Optimized Energy Performance** credit is a way to gain points for exceeding the **Minimum Energy Performance** credit. The heating, cooling, and dehumidification processes affect the assessment of this standard the same way they affect the assessment of the **Minimum Energy Performance** credit.

The **Thermal Comfort-Design** credit directly relates to the heating and cooling system. Since Green Building Certification Institute awards LEED points on the design of the thermal controls, the recycled waste heat and borehole cooling system would be under analysis in the assessment of this standard.

The **Enhanced Refrigerant Management** credit is relevant because the borehole cooling system meets almost all low-grade cooling requirements, minimizing the need for refrigerants and easing the probability of obtaining the credit. No other technologies gain recognition.

The **Thermal Comfort-Verification** credit has low relevance because it indirectly relates to the heating and cooling systems. In order to gain the points for achieving the standards, it is only necessary to verify that temperatures are consistently comfortable for people in the building. It does not specify any criteria about the way the building is heated, but the heating and cooling systems must maintain consistency in order to earn the credit. This offers some potential for recognition.

The **Site Selection** credit is relevant to the recycled waste heat process because it allows Tate Modern to use existing structures to draw its heat rather than add more construction for a heating system. This standard does not call for maximizing the use of site-specific technologies, but does call for the use of existing structures to minimize the production of new structures.

The **On-Site Renewable Energy** credit is very loosely relates to the innovative technologies. The standard refers to renewable energy, not renewable resources. The heating and cooling provide opportunity for the use of renewable resources, minimizing energy use.

This analysis shows that LEED can offer a different perspective to what is environmentally sustainable. BREEAM does not offer nearly as much opportunity to gain credit for innovative processes. If Tate Modern were to be assessed using LEED standards, eight separate standards reflect the innovative processes. In comparison, one section allows BREEAM to recognize innovation. Tate Modern is dedicated to sustainability, so in an effort to achieve sustainability the museum can draw from the LEED standards that do recognize the innovative features.

4.2 BRE Green Guides

The *BRE Green Guides to Specification* is an institution that recognises the innovation at Tate Modern. BRE does environmental profiles that rate the environmental impact of buildings. BRE states that the guides contain information for the impact of "discrete building elements" (BRE Global, Ltd, 2010). According to BREEAM Assessor 1, if BRE makes an environmental profile for Tate Modern, a description of the innovative features would most likely be included. Even though BRE is the same institution that implements BREEAM, the *Green Guides to Specification* are independent of the BREEAM assessment. Therefore, Tate Modern would not gain additional credit through BREEAM. This is still a way that Tate Modern can gain recognition for its innovative features.

Section 5: Conclusion

BREEAM is a robust system of environmental assessment. In order to obtain a higher level of accreditation, it is apparent that applicants must consider BREEAM standards throughout the whole process of design and construction.

BREEAM does not recognize innovation well. The limitation of the 2006 BREEAM manual and the standard application process for the 2008 BREEAM manual is the "tick box" nature of the assessment. This arises because BREEAM standards only concern the results. In addition, the "Innovation" standard is an independent section that requires an independent application process. This application process is deterring. This prevents project teams from applying for innovation credits, and therefore prevents BREEAM from recognising innovation. If BREEAM were to take into account how buildings achieve standards, this would offer opportunity to reflect innovation in every building assessed. Institutions such as LEED offer examples as to how BREEAM could recognise innovation throughout the manual, rather than in an independent section.

BRE has taken steps to address its limitations. BREEAM has evolved from a manual that did not recognise innovation into a manual that offered recognition in the 2008 manual. BREEAM can continue to evolve to address the limitations of how it recognises innovation. According to BREEAM Assessor 1, BRE is working in collaboration with LEED to create a universal standard that is easier to apply internationally. This offers an opportunity for BREEAM to implement innovation and site-specific credits throughout sections. This would be an improvement over the single innovation section.

Several institutions do recognise innovation. 2008 BREEAM does recognise innovation if applicants choose to apply for the innovation standards. Other environmental assessment schemes such as LEED offer recognition for innovation throughout the assessment. The BRE *Green Guides to Specification* offer environmental profiles that provide details of buildings and how they affect the environment. Although there is no accreditation involved, this is an avenue to gain recognition.

In order for a building to reach its potential of environmental sustainability, the project team must consider a robust environmental assessment method that will guide the construction in the right direction. The project team cannot limit itself to just one environmental assessment method, but must pull from multiple methods to account for the limitations. It is

possible to have a very sustainable building using innovative technologies and through the desire to move away from conservative practices. Buildings can be recognised for their environmentally sustainable features through several avenues.

References

BRE Global Ltd. (2006a). *Tate Modern Bespoke BREEAM Manual for Health and Wellbeing.* Unpublished manuscript.

BRE Global Ltd. (2006b). *Tate Modern Bespoke BREEAM Manual for Land Use and Ecology.* Unpublished manuscript.

BRE Global Ltd. (2006c). *Tate Modern Bespoke BREEAM Manual for Management.* Unpublished manuscript.

BRE Global Ltd. (2006d). *Tate Modern Bespoke BREEAM Manual for Materials and Waste.* Unpublished manuscript.

BRE Global Ltd. (2006e). *Tate Modern Bespoke BREEAM Manual for Transport.* Unpublished manuscript.

BRE Global Ltd. (2006f). *Tate Modern Bespoke BREEAM Manual for Water.* Unpublished manuscript.

BRE Global Ltd. (2010). *BRE: FAQs - the green guide* Retrieved June 15, 2010, from http://www.bre.co.uk/greenguide/page.jsp?id=2089

LEED. (2009). *LEED 2009 for new construction and major renovations* (LEED Assessment ManualUS Green Building Council. Retrieved from http://www.usgbc.org/ShowFile.aspx?DocumentID=7244

Max Fordham Consulting Engineers Consulting Engineers. (2009). *Transforming tate modern: Energy assessment*. London:

WORCESTER POLYTECHNIC INSTITUTE

Prospects for LED Lighting in Art Museums

By: Alexander Nittel

Edited By: Thaddeus Adams, Robert Cakounes, Kristin Smith

24 June 2010

This document seeks to identify the advantages and disadvantages of LEDs as perceived by lighting experts, curators, and conservators. It draws upon their perspectives to reach conclusions concerning the appropriateness of LEDs in art museums.

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Section 1: Introduction

Art museums face multiple needs when selecting a lighting system. The goal of sustainability is sometimes in conflict with preserving the art. Displaying the art optimally can sometimes conflict with preserving the art. For example, daylit galleries consume less electricity than those lit artificially. The fact that daylight contains harmful ultraviolet rays and that it has variable intensity mitigates the advantage of reduced electricity consumption.

This document will compare perspectives of those working with and in the museum sector on these issues as they pertain to LED lighting. These perspectives will be used to assess the prospects for LED lighting in museums in the next few years.

There are multiple options for lighting galleries. Some museums integrate natural daylight into their displays, whereas others rely on artificial light. Conventional artificial light sources include halogen and fluorescent lights. These technologies are mature and cost-effective. Each conventional method has advantages and disadvantages. A third artificial option is entering the market with its own unique characteristics. This option is the light emitting diode, or LED, and it has the potential to revolutionize museum lighting.

Twenty-first century museums must ensure that their lighting technology of choice is environmentally sustainable, presents artwork well, and preserves artwork. LEDs promise to meet all these criteria. LEDs are light sources that offer the potential to reduce energy consumption. In addition, some of them have the capability to display art comparably to other lighting technologies. Finally, they preserve art better than other lighting techniques.

Since LEDs have traditionally presented challenges in the presentation of art, the professional art museum community is uncertain as to when LEDs will be ready for museums. They are unsure whether LEDs can reach the aforementioned criteria in the next few years, or in the distant future. Since the lighting system will be one of the final systems added to the Tate Modern expansion, a projection of the state-of-the-art in LED lighting systems of 2012 will be forthcoming. This projection will help curators at Tate Modern understand why LEDs are the right choice for their galleries.

*Please see **Appendix 1: Glossary** for a list of key terms and their definitions.*

Section 2: Art Museum Lighting Systems

2.1 Issues with Daylighting

Daylighting of art galleries has both advantages and disadvantages. These characteristics concern how well the light displays the art and the effect daylight has on the longevity of an artwork. An understanding of the issues with daylighting provides a basis for the reasons for using artificial lighting, specifically LEDs.

Some consider daylight to have the best properties for displaying art. Its colour temperature of between 5,000 and 6,000 Kelvin is the standard that some lighting systems seek to emulate, according to Lighting Expert 1. Daylight provides a full spectrum that highlights all colours. According to Lighting Expert 1, outside light levels on a hot summer day can reach 100,000 lux, or 100,000 lumens per square meter. Artificial light levels in galleries are often lit at levels considerably less, at around 200 lux. In the opinion of Curator 1, historic paintings painted in daylight might look best displayed in daylight, the way the artist intended.

One may argue that daylighting makes a museum more sustainable, but the disadvantages of daylighting invalidate this point. Art galleries lit with daylight may require less energy and therefore could reduce a museum's carbon footprint. Nevertheless, daylighting is not an optimal method for displaying art. Over time, ultraviolet rays emitted by the sun have a deleterious effect on paintings, degrading the pigments, notes Conservator 1. According to him, solar heating and cooling cycles can crack the paint.

Daylighting also varies in intensity, which makes it difficult to achieve constant light levels in galleries that are daylit. Since the desired light level in a galley is much less than that of daylight, steps are taken to reduce the intensity of the light and to control its variability. Museums use a few light blocking techniques to achieve such light levels. There are active and passive methods of controlling daylight, according to Conservator 1.

Active methods are sometimes underutilized. One active method that is often not used fully is a louver system. According to Conservator 1, the louvers are controlled either manually or automatically. They allow the museum to control the amount of light that enters the skylights. Since weather changes frequently, museums have difficulty selecting the optimal setting for the louvers.

Passive approaches do not compensate for changes in daylight. They attempt to reduce its variability in intensity. For Conservator 1, holding the daylight level constant allows the museum

to select an appropriate setting for artificial lights. If the artwork in the gallery requires a lower illuminance, museums utilize shades to try to block all the light entering through the skylights. To distribute light throughout the gallery equally, museums use light diffusing screens, light diffusing membranes, and architectural features, such as ceiling geometries that hide the windows, according to Lighting Expert 1.

Finally, museums must take measures to prevent damage to the art from ultra violet (UV) rays. They install UV filters over the skylights or windows toward that end. Conservator 1, Lighting Expert 1, and Curator 1 all mentioned UV filters. Lighting Expert 1 cited a painting that, exposed to natural light for approximately thirty years, changed from being predominantly red to blue. Thus, natural lighting without appropriate precautions can change the appearance of artwork completely.

Given the disadvantages of daylighting, one perspective is to rely on artificial lighting instead. Artificial lighting is a known entity. It is controllable with the flick of a switch. The characteristics of the light produced by different types of lighting sources are well known. Artificially produced light has a consistent colour temperature and intensity. Daylight is variable, and it does not share these attributes. Lighting techniques, such as fluorescent, halogen, and now LEDs, share these advantages.

2.2 Fluorescent Lighting

Typical fluorescent lights do not have the correct properties to display art in a museum, according to Lighting Expert 1. One such property is colour rendering, or the ability of a light to reflect colour. It is measured on a scale from 0 to 100, with 100 being the best, according to Lighting Expert 1. Normal fluorescent tubes have a colour rendering in the low to mid eighties, whereas museum lighting should be in the nineties, notes Lighting Expert 1. As a result, in his opinion, the fluorescent tubes used in art museums use more energy than the typical tubes for home and office, but they achieve superior colour rendering.

Some fluorescent tubes, however, have a role in art museum lighting, permitting even lighting of gallery spaces. Conservators can select fluorescent tubes from a variety of colour temperatures. In Lighting Expert 1's opinion, fluorescent tubes range in colour temperature from 3000 Kelvin to 4000 Kelvin. Thus, the colour temperatures of fluorescent tubes range from warmer to cooler. Lighting designers use fluorescent lighting to achieve uniform ambient light

levels in galleries. Ambient lighting is appropriate when the lighting requirements of the artworks in the gallery are similar, according to Lighting Expert 1.

Museums must address the flaws of fluorescents in terms of lighting system design and lighting system maintenance. First, glare is an issue associated with fluorescent tubes that interferes with the presentation of art. In order to prevent glare, lighting designers specify that the museum place fluorescent tubes in light fixtures with light diffusing features. These might be grids or slats. Next, Museums must replace fluorescent tubes properly. If the tubes are improperly replaced, tubes of different colour temperatures might become mixed with those of the correct colour, creating an inconsistent colour temperature throughout the gallery. Finally, to prevent UV emission, the museum installs UV filters. Preventing UV transmission is critical when using fluorescent lights. The electrified gas and mercury vapour in the tube emits a UV light, and a phosphor coating on the glass converts the light to the visible spectrum. If the phosphor coating degrades, the tube could emit UV light directly.

*See **Appendix 2** for more information on the properties of fluorescent lights.*

2.3 Halogen Lighting

The following content was obtained through an interview with Lighting Expert 1.

Halogens have several advantages. The museum can easily replace halogen bulbs, and the museum has more control over the illuminance of artwork. Halogens are in widespread use throughout museums and components are widely available. Museums often use halogen lighting for spotlighting specific works. These fixtures are mounted on a track. This allows easy reconfiguration as exhibitions change.

Halogen bulbs also have some disadvantages. Halogen bulbs require UV filters. They have a shorter lifespan than fluorescent tubes, at 2,000 hours for halogen versus 7,500 - 20,000 hours for fluorescents (Fördergemeinschaft Gutes Licht, 2003; U.S. Department of Energy, 2008b). The main flaw of halogen bulbs is their efficiency. The efficiency of a typical halogen bulb is 19 lumens per watt, versus an efficiency of 30 lumens per watt with LEDs. This difference is the primary reason why there is interest in substituting halogen lighting systems with LEDs.

*See **Appendix 2** for more information on the properties of halogen lights.*

2.4 How LEDs Work

LEDs generate light by running a current through a semi-conductor. This action allows electrons to go across a gap, causing some electrons to fall to a lower energy level (U.S. Department of Energy, 2008a). When an electron changes energy levels this action produces photons, which we perceive as light. LEDs produce a very limited range of wavelengths of light, which are dependent on the material used as the semi-conductor. According to Lighting Expert 2, some modern LEDs use multiple phosphors to produce a light with a more evenly distributed spectrum.

*See **Appendix 2** for more information on the properties of LEDs.*

Section 3: Setting the Standards: Museum Lighting Requirements

The lighting experts, curators, and conservators interviewed have differing opinions of the ideal gallery lighting system. They disagree on the illuminance and colour temperature needed to display art best. Views on the ideal gallery lighting conditions appear to be personal preferences. Since the MLA lets museums determine their own lighting standards, it is not surprising that preferences differ. Lighting Expert 2 agreed that conceptions of the ideal gallery conditions are subjective.

Our interviewees tend to agree on the light levels appropriate for galleries. In their opinion, the ideal compromise between conservation and displaying of art is an illuminance around 200 to 250 lux. Curator 1, Conservator 1, and Lighting Expert 1 all mentioned an illuminance within this range. Lighting Expert 1 mentioned that if the work is "large", this range could extend to 300 lux. Artworks that are more sensitive would need 50 or 80 lux, claim Curator 1, Conservator 1, and Lighting Expert 1. According to Lighting Expert 1, 50 lux is the minimum light level necessary to display art.

It seems that everyone in the museum industry has a different opinion of what are the ideal gallery lighting conditions. Our interviewees had different notions of the ideal colour temperature of the light in an art gallery. Curator 1 thought that sunlight was the best form of gallery lighting. According to Lighting Expert 1, daylight has colour temperature of 5,000 K to 6,000 K. The opinion of Conservator 1 on the best conditions differed. He thought that the ideal colour temperature for light in an art gallery is 4,500 K. Lighting Expert 2 claims all the museums with which he has worked asked for lights with a colour temperature of 3,000 K.

Section 4: The Benefits of LED Lighting

LEDs are useful because they have advantages over conventional lighting techniques in areas relating to sustainability, art presentation, and art preservation. In comparison to earlier models, modern LEDs consume less energy, produce a more complete spectrum, and retain the advantages of a long lifespan and minimal art damaging emissions. Lighting experts project that LEDs lights will soon be at parity with halogen spotlights in terms of light output. They are already comparable to halogen spotlights in terms of colour rendering.

The museum professionals interviewed were mostly unfamiliar with LEDs, although certain benefits of LED lighting resonated with them. Interviewees ranged from being somewhat aware of the LEDs to being unfamiliar with them. For example, Curator 1 frequently acknowledged that he had insufficient knowledge of LEDs during our interview. Conservator 1 knew some basic information about LEDs.

First, LEDs are more efficient than halogen bulbs and some fluorescent tubes. A measureable quantity that allows efficiency to be proven is lumens per watt. Lumens measure the strength of light and watts measure the energy needed per second (U.S. Department of Energy, 2009b). LEDs offer more lumens per watt than the average halogen bulb, thus LEDs are more efficient. In addition, LEDs can achieve a higher colour rendering than fluorescent lights, according to information provided by Lighting Expert 1.

Second, LEDs are more cost effective than conventional technologies and have a lesser environmental impact because they consume less energy. The higher efficiency and longer lifespan of LEDs could help museums realize long-term reduction of emissions and energy cost savings. A common perception of LEDs is that they are still too expensive. This perception does not represent the current state of the art in LED technology. According to Lighting Expert 2, the payback time for an LED lighting system could be as quick as two years. Lighting Expert 1 agreed that one would measure the payback time in years.

Third, LEDs are easier to maintain than halogen or fluorescent lights. In the opinion of Lighting Expert 2, they are robust, as they do not have a filament that is easily broken. This attribute makes them ideal for galleries that the museum reconfigures often. LEDs also have a longer lifespan than incandescent bulbs and fluorescent bulbs, at around 50,000 hours (U.S. Department of Energy, 2008b). A longer lifespan has ramifications on the both environmental

and financial cost of replacing light modules and on the number of labour hours spent on maintaining galleries.

Fourth, LEDs do not emit UV rays. Lighting Expert 1 and Conservator 1 noted this fact, but Curator 1 was unaware of this advantage. Without UV rays, the pigments in the artwork degrade less. This a major advantage for conservators, whose aim is to preserve the artwork. Thus, LEDs eliminate the need for UV filters. Conservator 1 emphasized that LEDs are superior to both daylighting and fluorescents with the lack of UV rays. In addition, LEDs have the advantage over daylight of emitting a constant level of light.

Fifth, LEDs accommodate differing ideas of what constitute the ideal gallery lighting conditions. A common perception is that LEDs come only in shades that are too blue for gallery use. The truth is that LED manufacturers have created LEDs of different colour temperatures to meet differing preferences. For example, Lighting Expert 2 mentioned that his company produces LEDs with colour temperatures of 2,700 K, 3,000 K, and 4,000 K. These different colour temperatures approximate the light produced by incandescent, halogen, and fluorescent lights, respectively.

Section 5: Limitations and Barriers to Implementing LEDs in Museums

LEDs have some faults with respect to museum lighting. Earlier LEDs had the problem of an uneven spectrum, but this issue is now resolved. Since traditional LEDs emphasize one wavelength of light, not all the colour of the art is perceived as well as if it were lit with a method that emits more wavelengths. Lighting Expert 1 and Lighting Expert 2 disagreed on the extent to which LEDs emphasize certain wavelengths of light. Emphasizing one colour could negatively affect the display of the artwork. Lighting Expert 1 mentioned that LEDs highlight the blue in artwork since they output more blue light. Lighting Expert 2 disagreed. He claimed that the problem of over emphasizing certain wavelengths had been solved in new LED modules. He cited the use of multiple phosphors in the LED as a method of creating light with a more complete spectrum. Nevertheless, the fuller spectrum comes at a cost, he claims. Producing a more even distribution of wavelengths consumes more energy, making the LED lighting system less sustainable.

Since LEDs do not emit UV or infrared rays, most energy that does not convert to light converts to heat. This problem makes it necessary to maintain a proper temperature for the light fixture (U.S. Department of Energy, 2009a). If the temperature changes too drastically the colour of the light can change, and the lifetime of the LED will be shortened (U.S. Department of Energy, 2008c). Thermal issues with LEDs make replacing existing lighting systems more difficult. According to Lighting Expert 2, reaching the same level of performance as a halogen bulb would require an LED that produces more heat than a halogen bulb. Simply replacing the halogen bulb with an LED is unfeasible since halogen fixtures cannot accommodate extra heat. Halogen fixtures would be inadequate for the extra heat generated by an LED module, according to Lighting Expert 2. Thus, thermal management issues necessitate special fixtures for LED modules. Conservator 1 did not know that halogen bulbs cannot be replaced by LEDs with a 'plug n' play' adapter due to thermal management issues.

Cost is a key factor with LEDs. LED lighting fixtures are initially more expensive than halogen or fluorescent fixtures. According to Lighting Expert 1, it might be difficult to justify the initial cost of LEDs, depending of the availability of funds. Lighting Expert 2 agreed that upfront costs are a barrier to the implementation of LEDs. The expense of LEDs results, from their installation requirements. This is because the museum must install a new fixture for the LED

module due to thermal management issues. Most LED modules come integrated into their fixtures, meaning that the museum will have to discard the entire fixture once the LED module fails. Another concern of Lighting Expert 1 is that the lifetime of LEDs will exceed the lifetime of the fixture. In his opinion, some LED modules are expected to last beyond the guarantee for their fixtures.

Overall, the greatest impediment to the adoption of LEDs in museums is a lack of a thorough understanding of LEDs in the museum community. Interviewees indicate that they were generally unaware of the advantages and disadvantages using LEDs. Both Curator 1 and Conservator 1 noted that they needed to learn more about LEDs. LEDs are evolving at such a rate that even Lighting Expert 1 did not portray the most current information. He cited LEDs as capable of producing 700 lumens, when there are already some LEDs that can produce 1000 lumens, based on information from Lighting Expert 2.

In addition, the technology of LEDs must advance before museums adopt LEDs widely. For example, most LEDs do not yield light with the necessary colour rendering for museum use. Moreover, most LEDs do not output enough light for use in galleries, according to Lighting Expert 1. Our interviewees in the museum and art gallery community were somewhat aware of these flaws of LEDs.

Finally, the rate at which LED technology becomes obsolete is of concern to curators. LEDs are a rapid evolving technology. For example, as of June 2010 an LED module produced by Lighting Expert 2's company produces 1,000 lumens. Lighting Expert 2 claims that this output will double to 2,000 lumens by the end of 2010. Over the course of half a year, the output of this LED module will change from being insufficient for gallery lighting, to within the range specified by Lighting Expert 1, which is 2,000 to 3,000 lumens.

Section 6: Potential for LEDs in the Near Future

6.1 Improvements in Recent Years

LED technology is improving in multiple ways. According to Lighting Expert 1, manufacturers have solved some of the technical problems with LEDs. Xicato developed a method of making the colour of LEDs consistent. The process is to add a phosphor to the LED, which compensates for any colour temperature inconsistencies. Another problem solved is the low colour rendering of LEDs. Fixtures are now available that produce light with colour rendering in the 90s, which is appropriate for museums (Petluri & Sexton). One of these is the Xicato Artist Series XSM, and it produces light with a colour rendering that is comparable to that of halogen bulbs (Petluri & Sexton). The manufacturers note that, in addition to emitting low amounts of UV light, the XSM does not emit infrared radiation. As a result, artwork would experience less severe heating-cooling cycles, less expansion and contraction, and thus, fewer cracks.

LEDs are also improving in terms of efficiency. In the opinion of Lighting Expert 2, LEDs will reach a point at which they are more efficient than halogen bulbs. He predicts that LEDs will reach efficacies around 130 lumens per watt and outputs of 2,000 lumens by the end of 2010 . This is in the acceptable range for museum lighting, according to Lighting Expert 1. Lighting Expert 2 envisions that LEDs will gain acceptance in new areas in the future.

6.2 LEDs in Museums Now

LEDs are already in use in a London museum. The National Portrait Gallery has lit two galleries, room thirteen and room fourteen, with track mounted LED fixtures. Each cylindrical fixture features two rows of three LEDs, covered by a light diffuser. According to Lighting Expert 1, these fixtures use older LEDs that have a colour rending in the eighties. Switching the galleries to LEDs entailed installing new lighting fixtures, as the LEDs did not fit into the existing fixtures. Translucent skylights augment the lighting level in these galleries, thus determining the full impact of the LED fixtures is difficult for the untrained eye.

Observations at the National Portrait Gallery made the differences in the presentation of artwork in galleries lit by LEDs and conventional fixtures apparent. The LED fixtures appeared to emit a cooler, bluer light. The conventional fixtures illuminate the artwork with a warmer, more yellow hue. To the untrained eye, the disparity between the two lighting systems is only

apparent if one compares the galleries side by side.. By entering an LED illuminated gallery from one lit conventionally, a museum visitor might notice a slight change in which colours of the paintings are displayed most prominently. After a few minutes in the LED lit gallery, the difference is almost imperceptible.

6.3 Changes in Attitudes of Museums

LEDs are an increasingly viable option for museums. LED fixtures now exist that produce light with properties similar to those of halogen fixtures. In the past, selecting LEDs meant displaying the art inadequately. Now museums do not have to sacrifice their display standards. As LED technology advances, museums will have more LED options, and these products will become more affordable.

For LEDs to gain widespread acceptance in museums, some museums will have to become early adopters. These museums will have to experiment with products that are untested in museums. Perhaps the growing economic and environmental argument for LEDs will persuade museums to try LEDs. In such case, a change in museum attitude is not necessary, but a culture open to innovation is important for LEDs to gain acceptance in museums.

Section 7: Conclusion

LEDs are poised to enter the museum sector and to be ready for the Tate Modern expansion. LED technology is advancing at such a rate that LEDs will soon compare to traditional artificial sources. LEDs now exist that have a comparable colour rendering to halogen bulbs. The light output of LEDs is now approaching levels acceptable to Lighting Expert 1 as appropriate for spotlighting in art museums.

LEDs had some disadvantages, but they have been addressed. For example, LEDs once had the problem of an incomplete spectrum, according to Lighting Expert 2. That same expert claims that, by mixing phosphors, LED manufacturers can achieve a more complete spectrum and many different colour temperatures.

As LED technology advances, LED lighting will better meet curators' varying preferences. Interviews with those in the museum community and those serving them suggest that preferences of the ideal gallery conditions differ. Of those interviewed, conceptions varied as to what were the best colour temperature and illuminance levels for galleries. LED lighting experts claim that LED companies are developing modules that achieve a variety of different colour temperatures. Innovations in LEDs ensure that lighting designers will be able to meet curators' and conservators' preferences.

Appendix 1: Glossary

Term	Definition
colour rendering index	"The colour rendering index indicates how closely the colour of an object matches its appearance under the relevant light source" (Fördergemeinschaft Gutes Licht, 2003) .
colour temperature	"The light colour of a lamp is expressed in terms of colour temperature T_c measured in degrees Kelvin (K) … The higher the temperature, the whiter the colour" (Fördergemeinschaft Gutes Licht, 2003)
illuminance	"indicates the amount of luminous flux from a light source falling on a given surface" (Fördergemeinschaft Gutes Licht, 2003)
lumen	"a unit of luminous flux equal to the light emitted in a unit solid angle by a uniform point source of one candle intensity" (Merriam-Webster Online Dictionary, 2010a)
lux	"a unit of illumination equal to the direct illumination on a surface that is everywhere one meter from a uniform point source of one candle intensity or equal to one lumen per square meter" (Merriam-Webster Online Dictionary, 2010b)
luminous flux	"the rate at which light is emitted by a lamp. It is measured in lumens (lm)" (Fördergemeinschaft Gutes Licht, 2003)
luminous efficacy	"the luminous flux of a lamp in relation to its power consumption. Luminous efficacy is expressed in lumens per watt (lm/W)" (Fördergemeinschaft Gutes Licht, 2003)

Appendix 2: Artificial Lighting Techniques Compared

Technology	Light characteristic		Perception	Reality
Halogen	Colour temperature	~3000 K [1]	The preferred lighting technology for spotlighting in art galleries	LEDs will soon be at parity with halogen bulbs, making halogen bulbs obsolete
	Colour rendering	98 [2`]		
	Luminous flux	260 – 4300 lm [1]		
	Luminous efficacy	10 – 17 lm/w [1]		
	Lifespan	2000 hours [1]		
Fluorescent	Colour temperature	< 3300 K, 3300 – 5300 K, > 5300 K	Used for ambient lighting in art galleries, which may be used exclusively if paintings have similar lighting requirements	Fluorescents are still preferable for ambient lighting over LEDs. They also have a superior luminous efficacy to LEDs.
	Colour rendering	87 [2`]		
	Luminous flux	1350 – 5200 lm [1]		
	Luminous efficacy	75 – 90 lm/w [1]		
	Lifespan	7,500 - 20,000 hours [4]		
Modern LED	Colour temperature	2700 K, 3000 K, 4000 K [3]	LEDs have insufficient colour rendering and luminous flux, and too high of a colour temperature to light galleries.	State of the art LEDs already have sufficient colour rendering, colour temperature, luminous efficacy, and a lifespan better than or equal to halogen spotlights. Upcoming models will feature a luminous flux high enough to warrant the replacement of halogen fixtures.
	Colour rendering	98 [2`]		
	Luminous flux	400 -700 lm [3]		
	Luminous efficacy	33 – 40 lm/w [3]		
	Lifespan	50,000 hours [3]		

1. (Fördergemeinschaft Gutes Licht, 2003)
2. (Petluri & Sexton)
3. (Xicato, 2010)
4. (U.S. Department of Energy, 2008b)

References

Fördergemeinschaft Gutes Licht. (2003). *Lighting with Artificial Light*. Germany: Fördergemeinschaft Gutes Licht.

Merriam-Webster Online Dictionary. (2010a). *Lumen - Definition and More from the Free Merriam-Webster Dictionary* Retrieved June 20, 2010, from http://www.merriam-webster.com/dictionary/lumen

Merriam-Webster Online Dictionary. (2010b). *Lux - Definition and More from the Free Merriam-Webster Dictionary* Retrieved June 20, 2010, from http://www.merriam-webster.com/dictionary/lux

Petluri, R., & Sexton, R. *LED usage in museums and art galleries*

U.S. Department of Energy. (2008a). *Solid-State Lighting: How LEDs Work.* Retrieved May 18, 2010, from http://www1.eere.energy.gov/buildings/ssl/how.html

U.S. Department of Energy. (2008b). *Solid-State Lighting: Measuring Light Source Life.* Retrieved May 18, 2010, from http://www1.eere.energy.gov/buildings/ssl/life_measuring.html

U.S. Department of Energy. (2008c). *Solid-State Lighting: Why Does Thermal Management Matter?* Retrieved May 18, 2010, from http://www1.eere.energy.gov/buildings/ssl/why_thermal_mgt.html

U.S. Department of Energy. (2009a). *Solid-State Lighting: Comparison of Power Conversion of White Light Sources.* Retrieved May 18, 2010, from http://www1.eere.energy.gov/buildings/ssl/comparing_lights.html

U.S. Department of Energy. (2009b). *Solid-State Lighting: Using Light Emitting Diodes.* Retrieved May 18, 2010, from http://www1.eere.energy.gov/buildings/ssl/using_leds.html

Xicato. (2010). *Xicato - Making sense with LEDs* Retrieved June 22, 2010, from http://www.xicato.com/technology.php

CHAPTER 8: CONCLUSION

In an attempt to resolve the tension between museums and the sustainablility movement, we studied three aspects of the sustainable design of the expansion at Tate Modern. These studies addressed the changes as BREEAM evolves, use of LED lighting in museums, and the innovative technologies at Tate Modern.

Tate Modern's expansion is a sustainable building. The expansion scores well using a robust environmental sustainability assessment method. There are also aspects of Tate Modern's environmental sustainability that BREEAM does not recognize. Other institutions such as LEED recognize these aspects. Tate Modern proves that with modern technology and innovative thinking it is possible for a museum to become environmentally sustainable. For a more in-depth conclusion with respect to strengths and limitations and changes to BREEAM, refer to **Chapter 4** and **Chapter 6.** For a more in-depth conclusion with respect to other avenues to gain recognition for innovation, refer to **Chapter 6.**

Recommendations for further research include:

- Environmental sustainability schemes. This is important because an understanding of sustainability schemes is crucial while determining ways to be environmentally sustainable.
- Innovative and site-specific technologies. This is important because it allows applicants to understand ways to implement environmentally sustainable processes.
- Developing a way to tie together multiple accreditation schemes. This is important because no single environmental sustainability assessment method is comprehensive.

LED technology is progressing in ways that museums can implement that technology. LED technology is more environmentally sustainable than previous museum lighting techniques such as halogen. This concludes that technologies are advancing in a way that museums can maintain art, display art properly, and take steps towards environmental sustainability. For a more in depth conclusion with respect LED technologies, refer to **Chapter 7.**

Recommendations for further research include:

- Lighting technologies. This is important because it allows for an understanding of the technologies that would be most environmentally sustainable.

- Additional perspectives of museum curators and conservators. It is important to understand what the barriers to implementing environmentally sustainable technologies are in order to address those barriers.

This report determines that it is possible for an art museum to be environmentally sustainable. This requires the willingness to move away from conservative practices.

REFERENCES

Berg, B. L. (2007). *Qualitative research methods for the social sciences* (6th ed.). Boston: Pearson.

BRE Global Ltd. (2006). *Tate Modern bespoke BREEAM manual for Energy.* Unpublished manuscript.

BRE Global Ltd. (2006). *Tate Modern bespoke BREEAM manual for Health and Wellbeing.* Unpublished manuscript.

BRE Global Ltd. (2006). *Tate Modern bespoke BREEAM manual for Land Use and Ecology.* Unpublished manuscript.

BRE Global Ltd. (2006). *Tate Modern bespoke BREEAM manual for Managment.* Unpublished manuscript.

BRE Global Ltd. (2006). *Tate Modern bespoke BREEAM manual for Materials and Waste.* Unpublished manuscript.

BRE Global Ltd. (2006). *Tate Modern bespoke BREEAM manual for Pollution.* Unpublished manuscript.

BRE Global Ltd. (2006). *Tate Modern bespoke BREEAM manual for Transport.* Unpublished manuscript.

BRE Global Ltd. (2006). *Tate Modern bespoke BREEAM manual for Water.* Unpublished manuscript.

BRE Global Ltd. (2009). Retrieved June 9, 2010, from http://www.breeam.org/page.jsp?id=104

BRE Global Ltd. (2009). *BRE Environmental and Sustainability Standard: BREEAM Education 2008 Assessor Manual.* Retrieved March 18, 2010, from http://www.breeam.org/filelibrary/SD5051_4_0_BREEAM_Education_2008.pdf

BRE Global Ltd. (2009). *BRE Environmental and Sustainability Standard: BREEAM Industrial 2008 Assessor Manual.* Retrieved May 12, 2010, from http://www.breeam.org/filelibrary/SD5052_4_0_BREEAM_Industrial_2008.pdf

BRE Global Ltd. (2009). *BRE Environmental and Sustainability Standard: BREEAM Retail 2008 Assessor Manual.* Retrieved May 12, 2010, from http://www.breeam.org/filelibrary/SD5056_4_0_BREEAM_Retail_2008.pdf

BRE Global Ltd. (2009). *BREEAM: The Code for Sustainable Homes* Retrieved June 7, 2010, from http://www.breeam.org/page.jsp?id=86

BRE Global Ltd. (2010). *BRE: FAQs - The Green Guide* Retrieved June 15, 2010, from http://www.bre.co.uk/greenguide/page.jsp?id=2089

BRE Global Ltd. (2010). *BREEAM Master Bespoke Manual.* Unpublished manuscript.

Building Research Establishment Ltd. (2009). *bespoke BREEAM 2006 Tate Modern 2 Assessor Manual.* Unpublished manuscript.

Energy Performance Certificate (public and commercial buildings) - Planning, building and the environment - Communities and Local Government Retrieved June 15, 2010, from

http://www.communities.gov.uk/planningandbuilding/theenvironment/energyperformance/publiccommercialbuildings/energyperformancecertificates/

Fördergemeinschaft Gutes Licht. (2003). *Lighting with Artificial Light*. Germany: Fördergemeinschaft Gutes Licht.

LEED. (2009). *LEED 2009 for New Construction and Major Renovations* (LEED Assessment ManualUS Green Building Council. Retrieved from http://www.usgbc.org/ShowFile.aspx?DocumentID=7244

Max Fordham Consulting Engineers. (2009). *Transforming Tate Modern: Energy Assessment*. London:

Merriam-Webster Online Dictionary. (2010). *Lumen - Definition and More from the Free Merriam-Webster Dictionary* Retrieved June 20, 2010, from http://www.merriam-webster.com/dictionary/lumen

Merriam-Webster Online Dictionary. (2010). *Lux - Definition and More from the Free Merriam-Webster Dictionary* Retrieved June 20, 2010, from http://www.merriam-webster.com/dictionary/lux

Mingozzi, A. A., & Bottiglioni, S. (2006). A comprehensive and sustainable approach to the design of the retrofitting and enlargement of the National Etruscan museum 'Pompeo Aria' in Marzabotto, Italy. *International Journal of Sustainable Energy, 25*(3-4), 119-129.

Museums, Libraries and Archives Council. (2004). *The Accreditation Scheme for Museums in the United Kingdom.* Retrieved April 8, 2010, from

http://www.mla.gov.uk/what/raising_standards/accreditation/~/media/Files/pdf/2008/Accreditation_Standard

Petluri, R., & Sexton, R.*LED usage in museums and art galleries*

Polèse, M., & Stren, R. E. (2000). *The social sustainability of cities: diversity and the management of change* . Toronto: University of Toronto Press.

Regen SW. (2007). *Policy context - Regen South West* Retrieved June 18, 2010, from http://www.regensw.co.uk/south-west-england/policy-context/

Transport For London. (2006). *Transport Assessment Best Practices.* Retrieved June 16, 2010, from http://www.tfl.gov.uk/assets/downloads/corporate/TAGuidance_LQ.pdf

U.S. Department of Energy. (2008). *Solid-State Lighting: How LEDs Work.* Retrieved May 18, 2010, from http://www1.eere.energy.gov/buildings/ssl/how.html

U.S. Department of Energy. (2008). *Solid-State Lighting: Measuring Light Source Life.* Retrieved May 18, 2010, from http://www1.eere.energy.gov/buildings/ssl/life_measuring.html

U.S. Department of Energy. (2008). *Solid-State Lighting: Why Does Thermal Management Matter?* Retrieved May 18, 2010, from http://www1.eere.energy.gov/buildings/ssl/why_thermal_mgt.html

U.S. Department of Energy. (2009). *Solid-State Lighting: Comparison of Power Conversion of White Light Sources.* Retrieved May 18, 2010, from http://www1.eere.energy.gov/buildings/ssl/comparing_lights.html

U.S. Department of Energy. (2009). *Solid-State Lighting: Using Light Emitting Diodes.* Retrieved May 18, 2010, from http://www1.eere.energy.gov/buildings/ssl/using_leds.html

U.S. Green Building Council. (2010). *USGBC: LEED.* Retrieved April 5, 2010, from http://www.usgbc.org/DisplayPage.aspx?CategoryID=19

Xicato. (2010). *Xicato - Making sense with LEDs* Retrieved June 22, 2010, from http://www.xicato.com/technology.php

APPENDIX A: QUESTIONS FOR BREEAM ASSESSORS

1. There has been a growing focus on environmental sustainability. How does BREEAM stay relevant to the ever-changing field of green technologies?

2. Our research indicates that there is a conflict between preserving art work and achieving environmental sustainability. What was the challenge with creating a set of standards for an art museum?

3. We understand that art museums are naturally environmentally unsustainable, but everyone has their responsibility to preserve the environment. Should art museums be held to the same standards as other buildings? Why? Why not?

4. Since there is no area for innovation section of the 2006 'bespoke' manual for Tate Modern expansion, is there any way for Tate Modern to achieve any more credits for innovative technologies? Could innovation credits be integrated throughout the BREEAM standards?

5. How is something deemed innovative?

6. What does one have to submit on the application on the Innovation Application Form?

7. We understand that innovation standards are uniquely constructed for individual projects. What does an innovation assessment cost? Why?

8. The Green Building Council of Australia has a defined limit for how long a project can take to be finished. Since the Tate Modern is currently following the 2006 standards and is to be finished in 2012, how does BREEAM ensure that they are still following the most current regulations?

9. Do you feel BREEAM is used as a way for steering projects in the direction of environmental sustainability, or is an assessment of the projects after plans have been implemented?

10. What are the limitations of the 2008 BREEAM criteria?

APPENDIX B: INTERVIEW WITH BREEAM ASSESSOR 1

…*explanation of project*…

BREEAM Assesor: I have just been handed it, I do not know much about it you might know more than me…

RC: What are your feelings on BREEAM; do you feel it is an effective system?

BREEAM Assesor: Yea, it's kind of …one of the few standards out there...it really relates to best practice [with the environment]…within sets or requirements…gauges the building… it's valid in its way of assessing a building

RC: how does BREEAM keep up with current trends in environmental sustainability? It is an ever growing… field, how often are the BREEAM standards updated? What goes in the process of changing standards?

BREEAM Assesor: in terms of updates, they generally happened…different schemes happen different times the offices for example …happened quite a lot between 2000 and 2008… a lot of progression in that field…generally it's every 2 years on average at the moments and that's pretty much across the board…often driven by big changes in England…for instance partel…the conservation energy section…they always update with that…basically whenever…it's two years cause of the legislation, standards gets updated all the time…they research the stuff, trying to keep up with best practices…always trying to gauge a building…go above regulation and you'll get credit if you go above regulation you'll get credit

RC: so there is like UK legislation and BREEAM goes above that?

BREEAM Assesor: yea for several credits, like for partel CO2 it gauges against the partel calculations the way the building's built credit…above that standard…generally its…monitor all the aspects…land use and ecology, waste management, keep your eyes on those sectors…keep your eyes on what's been published…don't do much themselves… look at what other people are doing…base their credits on other professional institutions

RC: so it is like [a collaboration]

BREEAM Assesor: exactly

RC: of the other current…

BREEAM Assesor: Building service energy…sivcey[?] is the main institution…follow their standards…seen as best practice

TA: Has there ever been a case where BREEAM ever based their standards on a new technology? Or are there any other driving forces other than legislation?

BREEAM Assesor: I haven't seen…had made a separate credit for something coming out...but do include…heat pumps…example gas fired heat pumps…acceptable technology, for example…is that what you were asking?

TA: yea, I was trying to see if there were other driving forces

BREEAM Assesor: well, there's technological advancements, but based on legislation… but seeing new technology coming out I'd keep an eye on that…pretty much keeping aspects the same, not much inclusion…last five years…core credits the same

RC: yea, minor details

BREEAM Assesor: some big changes

RC: what buildings have you assessed?

BREEAM Assesor: um, several schools in and around London area, office in Lincolnshire, timber framed, rating well in material sections…sports center refurbished [Victorian building]…assessing Tate Modern at the moment, pretty big…another sports center that's kind of small…mainly do schools and offices…some residential stuff…do industrial retail

RC: so you do what max Fordham does?

BREEAM Assesor: yes, about 80% are home engineering jobs…mostly our engineering jobs get assessed

RC: since you are working on Tate, what are the challenges since museums are not sustainable buildings?...What are the challenges with creating a good sustainable standard for the Tate

BREEAM Assesor: haven't even looked at it…given it a week ago…[repeat question]…all the credits set the same…pretty much the same…obviously in terms of a museum…probably look at day lighting…how you ventilate space…so I guess...yea…In terms of designing strategy that's going to get you achieved a criteria that's difficult …developing the criteria…Tate Modern is complex, have to assess function areas separately…imagine that's the key bits…

RC: so there are multiple standards depending on the areas? The offices will be assessed separately from the gallery space?

BREEAM Assesor: yea exactly

RC: all of those are mentioned in bespoke?

BREEAM Assesor: It doesn't clearly state that…don't list it in the manual they give it in the spreadsheet…breaks it down where which credit is earns…for offices you have to get daylight, you have lighting zones … thermal zones…[for gallery space] they wouldn't expect you to use zones, so you wouldn't have that credit…

RC: is that type of setup separate is not normal for BREEAM usually it's like the whole building

BREEAM Assesor: yea, normal schemes…say it is an office it is applied to an office… if a building does not fit a particular scheme then you use bespoke

RC: So this does happen other times?...The aspect of [different areas being assessed]?

BREEAM Assesor: Yea…

TA: … Since museums are typically not sustainable, do you think it is fair to hold them to the same standards as an office building, where it might be easier to be sustainable or should they still be held accountable for their emissions and energy use?

BREEAM Assesor: I think it is a bit unfair actually. The main example would be the CO2 emissions credit …it's on the same scale [for Tate}…it's a bit fairer now because you compare a

light for light building in the calculations so you can get a percentage approval that's relative to a base case but for example having a natural ventilation credit for a museum doesn't seem very fair perhaps cause it's not done standard in that.. That is one thing with BREEAM is that they do not make the assessment quite bespoke enough for a building. That is sort of a general comment

TA: Do you think there is other ways they could be held accountable…Do you think it is a little too easy on museums in any area?

BREEAM Assesor: perhaps no…maybe, depends on where the museums located and what the sites like…generally a museums in a city, in an urban environment…that does apply to most buildings as well…for the ecology credits …they're valuable credits and you have no real way of achieving them …as long as you have any landscaping [you can try]…generally [museums] don't have external landscaping but those credits are always in there…also they're unfair for some transport credits too…cyclers provision: if it's a massive gallery, lots of people going to it… you're supposed to base cyclers provision based on 10% of visitors a day… seems high, generally people wouldn't cycle to a museum in central London, same with a theater… you can get it reduced if you try hard, but that's one they try to stick in there…

RC: With the CO2 emissions…in the 2006 they are based off a percentage decrease whereas in 2008 they are based on a hard number

BREEAM Assesor: it is the anti-performance certificate rating... it is a dimensions figure they take from the CO2 index from PPC(?)

RC: that set number is a benchmark based on…

BREEAM Assesor: it's a comparison with…calculate a reference building…based on the same dimensions and same floor space of the building…basically same drawings of the buildings…produce…I forgot the exact calculations…based on previous building regs from 2002

RC: …so it is planned directly towards the building?

BREEAM Assesor: yes

RC: looking at Tate Modern…what is the likelihood of it reaching this new benchmark?...

BREEAM Assesor: Probably not…as far as I understand how the credits relate…in short it probably wouldn't get as many credits…why that would be, it's quite a complex answer…I could probably explain it to you better in an email…

RC: Is there any document that shows the logic behind updated standards…Are there documents you could send us…?

BREEAM Assesor: I think two things…first when BREEAM started [in 1990] up until 2006…it set the weightings of each category to be the same…when BREEAM was getting more popular in 2004, people …thought energy should be worth more…it changes in 2007… because stable homes made that standard…those are two reasons why [they separated the grading of energy and transport]…the reason they separated materials and waste…tried to align it a bit more with what the government was doing…trying to make BREEAM [align] with sustainable buildings…there could be other reasons I don't know of…I'll send [you documents]

RC: Moving on…the introduction of the innovation credit, how is that assessed…?

BREEAM Assesor: haven't been in involved in it yet…could be anything that relates to any of the sections…pay 1000 pounds and offered explanation…quite vague…it kind of shows you they've made it quite an open window…don't mean to be cynical…more innovation they get the more they can charge…

RC: so it is...a document and it get's yea'd or neigh'd?

BREEAM Assesor: that's all I know about it

TA: So since there's no innovation standard in the 20006 standard.. Do you see any other way BREEAM could recognize the innovation…?

BREEAM Assesor: I can't think of anything that would…BRE might have something else…they do things called environmental profiles they do of a structure of something they did a bespoke rating…product specific…could be a way to gain credit…use green guide specification which is quite generic if it doesn't fit into it you can't do a bespoke rating on it…in a way it's a way to get additional credit…similar to innovation section now…

TA: in the realm of BREEAM do you see the possibility of integrating innovation throughout other sections…possibly in the future…[like LEED]…?

BREEAM Assesor: That's sort of the same that HQE has…I wouldn't be surprised if they did…probably would be an attractive things actually…BREEAM is trying to do things internationally….BREEAM has very set [quantitative] standards…are trying to align with USGBC…the way I see it they're trying to align things a bit more…it would be attractive to design teams and clients to have those options…but I don't know if they're going to do it

RC: In 2008, they're introduction to post construction regulations…

BREEAM Assesor: that does make it more robust…[gave example of project without post construction]…BREEAM doesn't want to admit [the faults of not having it in the past]…people have to follow post construction…does the whole assessment again…make sure they follow through…do site visits to take photographs…

TA: is there any effort to go back and do post construction [with 2006 and earlier]?

BREEAM Assesor: it's optional and has happened

TA: do they get recognition for doing that?

BREEAM Assesor: no…a lot of trust put into it…generally a majority of the projects have implemented things…there isn't anything to distinguish a ptr…in 06 they did it in homes…because they were social housing…and they wanted to …reinforce that

TA: Is there a way BREEAM can do something similar [to GBCA]…what's there to assure that assessments are current?

BREEAM Assesor: they have 5 years after 2006 expires, so …2013 [for Tate Modern]

RC: What if there's a huge delay and [they don't meet the deadline]

BREEAM Assesor: they're pretty strict…unless they really pleaded…they'd have to be reassessed under a new scheme…

TA: …do you feel like BREEAM is moving in a direction where people aren't using it just as a tick box…?

BREEAM Assesor: yea, most people are…they're using it to form their design…people who actually read the credits…it all refers to best practice…some people do slightly resent it…some architects…I think generally yea, it's being used [the right way]…it follows more general standards…it's becoming quite prestigious…if a project is going for excellent..that's when designers get excited

TA: Do you see any glaring limitations with 2008 BREEAM standards…?

BREEAM Assesor: the credits where you get assessed with proximity to amenities…usually you're completely out of control of what's around you building…they've removed it from sustainable homes…bespoke aren't quite bespoke enough…it's just a huge list of credits that apply some to retail, to offices…as I explained earlier…some buildings it just doesn't quite fit… it hink also this process is far to paper tentive and cumbersome…LEED is a lot more streamlined…online…live updated online kind of like a website…your assessment you fill out an update and once you complete it…BREEAM, there's too much onus on the design team…writing reports that I think its unnecessary… too much paperwork, should be streamlined a bit more…LEED the whole design team has access so [anyone can update]…BREEAM has no central place for documentation…time on their hands that aren't accounted for on design team fee…did a study…for an architect adding 1 to 2 % to their time which can equate to 7000 pounds…soft costs too great…something they should address…make it a bit more efficient…

TA: if you could just send us an explanation on the changes, etc…

APPENDIX C: QUESTIONS FOR CURATORS

To start we will provide a brief introduction and overview of our project. We are currently working with Tate Modern and more specifically the expansion project. Our task is to determine a persuasive argument for or against the use of LEDs in the lighting of museums and galleries.

As of now, we know some of the technical specifications for the conservation and presentation of artwork, i.e. oil paintings use lighting no more than 250 lux and different types of artwork require different color temperatures in the lighting.

Our current goal is to gain the opinion of individuals in the art world on LED lighting, to learn about the reputation of LEDs, and to understand how well LEDs present art.

1. We understand that there are universal standards implemented in the maintenance of an art museum. What are museum standards for lighting? Where can we find more information on museum standards for lighting?

2. We understand that currently you have some artifacts lit with LEDs. How does the color temperature of the LEDs affect the displayed color of the artifacts?

3. How important is artificial lighting to your gallery in relationship to daylighting? What are the key criteria for lighting when developing an exhibition in terms of lighting? To what standards do you hold your lighting?

4. What factors do you take into account when choosing lighting?

5. What are you trying to achieve when lighting a gallery? Are your methods of lighting geared more towards conservation or presentation? How so?

6. We are aware that you installed LEDs in an exhibit in 2007. In addition, LEDs are currently a rapidly advancing technology. What is the most modern model of LED you use in your exhibits and galleries? Do you make an attempt to keep your galleries up to date with current LEDs?

7. We understand that LED lighting is evolving into a new form of low energy lighting, but curators have some concerns when implementing LED lighting in art museums and galleries. What are the advantages to LED lighting in an art gallery? What are the disadvantages to LED lighting in an art gallery?

8. As of now, we do understand that there are some disadvantages to LED lighting - the relatively low color rendering and the low brightness. Do you feel that LED lighting could move in a direction that the advantages outweigh the disadvantages? Do you have an opinion of when LED lighting might to improve to such a level?

9. Which lighting consultants do you prefer?

10. To your knowledge, are there any other galleries or art museums that are using LED lights now?

11. We understand that different artwork requires different temperatures of light to display it properly. Could you explain how color temperature affects different types of media? What are different lighting requirements for different media?

12. What order of preference do you assign to the available lighting technologies, when planning an exhibition?

APPENDIX D: INTERVIEW WITH CONSERVATOR 1

Conservator 1: Yeah…so…there are some works that are not light sensitive at all, of course stone … metals … So we essentially categorize those works, and there are quite a number of things that we know have got to be displayed … with works that go at a higher level … So there's a process of discussing the … sometimes whether works can remain … on display for a certain period of time, so the light sensitive works we say can stay on display for … 2 years in every four. That's a strange of expressing it but…

RC: Is it like cumulative, so you could have six months on, six months off and have it out there for eight years?

Conservator 1: Whatever time, because we've got four sites, people wanting the same works, and so someone may have had it in one exhibition and they want in another exhibition, so it's workable to say it stays up for 2 years … a maximum of 2 years in a four year period. And the registrars can check on that, and they say when things have go to come down … The logic of that means that things last twice as long … Archives say one year in four … so our archives are given less light than our collection, and that's because [they argue that things were not acquired for display …have to last longer] … I could give you – send you that actually … You know, we've got some lighting instructions …

RC: …We talked to someone at Whitechapel Art Gallery, and we understand they have a different mentality – museums are more concerned with preservation … conservation … of the art work, while they were more concerned with the actual presentation …

Conservator 1: It's not their work is it?

RC: Yeah … and ah the artist is usually alive for their's, so they can …

Conservator 1: Well a lot of ours are still alive.

RC: um

Conservator 1: …But … yeah, once it's acquired and bought and paid for and it becomes the property of the museum, of course, yeah obviously that does make a difference.

RC: As such, like ah …One thing we understand, is that the art would be viewed best under daylight, but it's horrible for the actual conservation of it is -

Conservator 1: Well as I said to you before, I don't agree that [art] looks best under daylight, and I have never seen anyone give me a convincing argument … Very happy to sign that.

RC: …That's what we're trying to decide.

TA: What would you say is the best … type of lighting –

Conservator 1: …I sent a document to the TM2 people earlier on. It's a warmer light, 4,500 K, something like that … rather than six or seven thousand which is … daylight.

RC: And you agree more with spotlighting over ambient lighting?

Conservator 1: … Well from a conservation point of view, yeah … I acknowledge that the building needs to be lit … the 200 lux level – the 50 lux level is the minimum that anyone can see the work by. For that to that to work, it has to be spotlit, and you can't really put any ambient lighting. And for paintings generally, that's why we go for 200 lux, that is there to allow … some ambient lighting from the [window] to the room, but the more ambient lighting you have, the more reflections you can have, the more … your light in competition with the light for the object. But it's a museum, it's here to display objects, so the primary issue is to light the object, I would say, but I agree not the only one.

RC: How much information do you actually know on LED lighting –

Conservator 1: Not a huge amount.

RC: Not technical specifications, but like color rendering, color temperature … just how much you generally know on it.

Conservator 1: Well … I know the principle of how it works, and that it's not a continuous spectrum, and that you really need to have fluorescents there to warm it sufficiently from the basic one that's always used … but no – I don't – very weak on it.

RC: We were just wondering, what do you believe– besides the environmental impact of LED lighting – do you believe there are any other advantages to incorporate them into museums or galleries in general?

Conservator 1: …I've never seen – I don't know whether they can be used effectively for ambient lighting. I don't know whether that's true or not, so that would be an interesting question…

RC: They would be used mainly to replace halogen bulbs with spotlighting, or –?

Conservator 1: Yeah, I think that's all I've seen … and it does that, I think, reasonably effectively.

RC: …other than the environmental impact, are there any other advantages that you see for the use of LED lighting? Or are they generally just as good as halogen, not really better, but because they're more environmentally friendly?

Conservator 1: Oh, I see. Ok. Well they can be quite directional, can't they? So perhaps even more directional than ordinary spotlights. They have almost a parallel beam, rather than spreading. Whether that's – that probably does not have a huge number of applications, but … No, I don't think that there is any other advantage to them that I know of.

RC: So the big push is environmental?

Conservator 1: Well yeah, energy use.

RC: Just from the conversation before, you seem very convinced that LED lighting will be at the point you want it to be for TM2?

Conservator 1: Well, I know it's going to be better.

RC: [It did seem] getting better faster –

Conservator 1: … yeah, than fluorescent. That would be … a disaster, so this better work. And if it doesn't work, then you have got to go back to – you've got systems that could be used as spotlights, so you just replace it with a tungsten halogen.

RC: What needs to be done before it gets to that level, what are still the falling points, in your opinion, of LED lighting?

Conservator 1: Well, I would like to see more about the actual spectrum that they produce. Some people say they're terrible. I don't think they're terrible.

RC: There's the newest one – we got this from Arup lighting - … one that has above 90 on the color rendering.

Conservator 1: That's pretty good.

RC: That's where it needs to be. Other than increased spectrum, do you -?

Conservator 1: … To have an acceptable warm - something that 4,500 K range … to go for what I think is the right level, color temperature.

RC: So about 4,000 level, alright…have you seen – so you have seen LEDs used? Were they samples or were they actual exhibits?

Conservator 1: Yeah, we got some samples and we looked at the works in the studio with them, and it was all very subjective. But I did that with some paintings conservators who were equally – their response was, in think, the same as mine: Ok, you know I can't detect the dif- I think if you went into a room, you wouldn't detect that it was an LED light if you couldn't see the light source.

RC: We visited the National Portrait Gallery, which is currently-

Conservator 1: Yes, they're doing some work. I haven't been over to take a look yet.

RC: And as far as we could tell – when you stood in-between the two galleries, the one that was being lit by LED, and the one that wasn't, you could tell the difference, but –

Conservator 1: I must go and have a look at that one…

RC: -they're using an older version of the LED, a cooler one. It has more blue in there than the ones expected to be used for Tate Modern.

Conservator 1: Right. Ok. I think blue is…

RC: Blue isn't good, so it really needs to be warmer light.

Conservator 1: Because again, you're used to seeing spotlights – spotlights are never blue. I don't think. I've never seen one, unless its got a blue filter on it. And of course there's low UV too, virtually no UV, [and that] is an advantage there. Yeah, that is actually enormously useful, because if you've got fluorescents and if they're not housed in any way then you don't have a filter there, so you've got to make sure the filters – that you put those sleeve filters on. But it's, again, it's a huge problem of making sure that happens. So yeah, that's important.

RC: We understand that LEDs are weaker …

Conservator 1: Weaker?

RC: They don't produce –

Conservator 1: as much light?

RC: bright enough light …

Conservator 1: …Ok, I'm surprised…For ambient lighting yeah ok…

TA: For spotlighting-

Conservator 1: -Yeah I suppose an issue.

RC: Does the display of blue light, or too cool a light –

TA: We ask if there's any way they see they could fix that with LED lighting.

Conservator 1: Ok, right.

RC: So just to summarize and make sure I haven't missed too much, work is usually placed in with work in a similar structure, and the lighting is based on the most, the weakest I guess, I'm trying to think of this properly.

Conservator 1: The most sensitive.

RC: The most sensitive. The lighting and the conditions is based on the most sensitive art, and then –

Conservator 1: Well, I can – if you give me your email address, I'll send you our instructions for lighting requirements …

RC: I don't feel that there's much more you've been extremely helpful…So we just need to check if it's around 4,000 K for the color temperature … is 4,000, 5,000 is –

Conservator 1: Again, I could send you a copy of the paper that I've already submitted, but I think it's quite convincing as an argument.

…

Conservator 1: Yeah, well I do hope that you come up with a system that works, because certainly when these things get in place, they never get changed, there's never any money afterwards to [use to] change them, so you've only got one chance to get it right.

RC: With the long … usage of LEDs –ten years- it's – what happens if they get better? What happens if there are potential problems? Would you replace them or would you wait for the end of the ten years? It's just a curiosity…

Conservator 1: Well, probably we would be introducing them elsewhere, I imagine if it's successful … if they can be fitted into existing [component] lighting systems.

RC: That's one of the problems, they require their own fixture … as they are now.

Conservator 1: Why are they not producing – is it impossible to do that?

RC: The way –

Conservator 1: Just in terms of sales, you'd have thought they could make a huge …

RC: Currently, actually you buy them all as one – you buy the fixture and the bulb as one – and they're trying to move away from that where you can actually replace the bulb …Just because of the way it works –

AN: It's the heat issues.

Conservator 1: Electronics.

RC: It's the heat issues. If it gets too hot, the LED changes colors.

Conservator 1: Ah, ok. I must read up more about them … I was waiting for them to come up with something that was kind of – I guess these things just continue changing – I was hoping there was something you could focus on and say "Let's look at that one."

RC: …There do seem to be some good ones coming out, from our limited research … There's still the issue of [a] long shelf life and having to replace the … whole fixture as of now.

Conservator 1: Well, I would go further than saying that they're a good idea. I would say they're at least already a better idea than fluorescent lights. And, I think they would be a better idea than daylight, because daylight doesn't give us the light color temperature that we want, and it invariably is uncontrollable, which is our main concern … And get rid of all the windows. I think windows are for looking out, not for letting light in.

RC: The way the US usually runs its [system] with black boxes and spotlights on everything is generally good, or –

Conservator 1: No, no. You do need ambient lighting and you certainly need it outside the main galleries, the connecting areas, definitely. But, yes you may well need ambient lighting for certain types of displays, too. How would you deal with that? Most of the systems that we've got – well no there's one of the galleries I know in the current plans that has four skylights … but mostly they're not …

RC: At TM2?

Conservator 1: Yeah.

RC: There's the fifth floor has half the gallery … is daylight but it has the … louvers that block the light from the proper angle, it goes through a UV filter and then a –

Conservator 1: That's going to look horrible. Did I say something wrong? … I mean there's huge pieces of plastic floating on top. That will look nasty. But why to get daylight in? The hoops we jump through to get something which people can call natural daylight, it's just nonsense. Is that still – I thought people would just look at that and think "We can't seriously build this."

RC: Apparently they've done it at a lot of places.

Conservator 1: They showed what they'd done and it looked just as bad there. You can quote me on that.

APPENDIX E: INTERVIEW WITH CURATOR 1

RC: Really?

CURATOR 1: Yes, I think I've always honestly… incandescent lighting. Um, obviously with… I don't think I've ever seen (It's integrated?) in a lot of artwork maybe… but I've never seen it as a primary lighting source to light a space.

RC: Do you think that's just like… would you be willing to like… I don't even know how to phrase this…

CURATOR 1: Just phrase whatever the question is

RC: I don't know I was just trying to start a conversation

KS: Okay, we understand that there are universal standards implemented in art museums but what are the museum standards for lighting?

CURATOR 1: The concerns regarding lighting… light of course in a way it's a material when you construct. All good museum space is about having good light. It's a crucial thing. There's … are conservation standards for lighting and not lighting for which the museums were designed. So, effectively, it's very difficult actually to go above 200 lux um unless you've got a living artists who is very willing to just go with it, I mean it's perfectly fine for oil paintings but as soon as you're in a museums environment um conservators would prevent you from doing so. So you need to design it really… consideration standards rather than to what would make a beautiful space. Two very different things. Um you need to be able to control the temperature because photography… pinker than painting which of course is more yellow. You need to be able to increase and regulate discrete areas of building within one space so you can have one area fit for painting another area fit for work on paper and in such a way that ideally… you're not aware that you drop into a cooled off shadow… over ambient light is okay. It's a tricky one because when you see our galleries which were built in 1901 so they have glass ceilings. When they are completely untampered … the light is fantastic. Absolutely fantastic. Artists love it. It's not

something you would ever get away with normally in a museum environment. It's purely because someone wants it.

KS: Do you know where we can find more information on museum lighting standards?

CURATOR 1: Yes you can go very basic to um go and look at government regulations which tell you what conservation agreements are in order to get state indemnity for (loans?) so we are all titles. Nobody would be able to talk to you about better light than artists. And the big problem is that because artists are very attune to lighting, they will create light situations where they work which is perfectly in tune with their work which museums will not be able to mirror after.

KS: Thank you. To what standards do you hold your lighting?

CURATOR 1: uh depends entirely I mean it's um the first guideline of course is conservation. It's practical demand. If it's indemnified, you can only go so far. It can only be 200 lux on the paintings or 250 maximum and 80 on works of paper and then you begin to try to make it as bearable as possible. It's completely different when you work with someone like now, the artist at the moment, Richard Howerson, who actually is perfect with the glass to be open and accepts whatever it does to the work.

KS: What factors do you take into account when you're choosing lighting?

TA: Different styles of lighting…

CURATOR 1: Well, it depends on what you see working and what doesn't work. I've never seen a space which was ambient lit with artificial light consistently and it worked, so in the end everyone begins to introduce spotlights, even if you don't want to have that erratic thing. In order for the object, particularly when the rest of the room needs to be calmed down to get to the 200 lux, you almost can only do it by giving the work a little bit more of a lift so that you feel the room swings away. There's a consistent problem with corners, most gallery spaces have really awful corner lighting. They're dark, which I hate. And fundamentally of course, is a philosophy of the museum, you can go to the ... if you look at the extreme case, the (melio?) collection in Euston, the light is really strong but it's understood that the work is only out for six months and then everything goes off display. As all light damages are cumulative and they've prioritized the

quality of light over the rhythm of the display…. The entire building has… but its daylight all the way through.

KS: We understand that LED lighting is evolving into a new form of low energy lighting but there are some concerns when implementing LED lighting within art museums and galleries. Do you know what the advantages are of LED lighting in an art gallery?

CURATOR 1: No.

TA: … you haven't heard anything…

CURATOR 1: I've seen, I mean funny enough, I've seen artists presenting work in LED lighting, um, and it's got a very particular quality to it. I mean it's because they are into those tubes so it's got a muffled quality to it and I know you can do the whole thing with coloring it, changing the temperature, but… it has a very particular quality to it… it's like looking at an LED screen.

KS: Do you feel that LED lighting could move in a direction so that the advantages outweigh the disadvantages of LED lighting?

CURATOR 1: No. I have no idea. All I know, is that in the end, the best light is daylight, that's quite reassuring, the… honest you are about the other lighting conditions, so do you try to gloss over the fact that it's artificially lit or do you do it very impractically(?). Museum... neon lights. In the end, I think the key to it is how flexible it is because you never know what goes in them. So you will always need to have ways of how to get individual works.

KS: Would you expect LED lighting to improve to a level that would be used in a museum.

TA: Well, that's…

RC: That's… he doesn't know.

CURATOR 1: Who knows?

KS: Okay.

RC: Just to give you some background information on what we've learned about LED lighting right now, it currently, there's only one or two types that can produce color rendering above 90 percent or the score of 90 I guess… there's only one or two. They're state of the art. They only came out within the past year. Currently, the only problem they see with LED lighting is that it's not powerful enough. It can't light the space as well. Thinking of that, would you be willing to even do a sample gallery with LED lighting, just to see how it works or are you willing to start using LED lighting knowing that they're starting to get into the right color range…

CURATOR 1: It's a tricky question cause of course, you I mean if you ask me directly and personally here and now, it's a very tricky question because if you work with an artist, no artist will be a guinea pig. So that's your first challenge, so I would imagine if you want to actually have an informed response, try to find an artist who, and most people are, ask them what light they use in the studio… much more than doing it in a public space.

RC: Just out of curiosity, I guess all of this is curiosity, but would changing the gallery lighting be most useful by changing the perspective of artists first, if we address artists and see if they can start moving towards lighting in their studios and then they come out and they are like "we like this lighting" that would be the easiest way to change?

CURATOR 1: Yes, yup.

RC: Can you rephrase that in your own words?

CURATOR 1: Well I think it's very simple. If a museum is a repository of history, you actually look after artifacts made by somebody else in a particular context and to whatever degree you probably … conventions of modernism probably of … galleries you come close to where that work was produced and certainly over the last 20 years. And Tate Modern is the best example of that. Tate Modern is a repurposed industrial building which is a classic studio environment. It's not a new architectural… and the new building will be slightly different. But a lot of what underlines it and certainly all commercial galleries that have been built over the last 20 years, most of the big… they all have emulated studio conditions in some way or another. Maybe not an idealist studio… so I think the closest you get to getting by and into this is possibly by working with an artist who has a great awareness of light and who has a very professional studio

and there are quite a few of those… big studios around. And artists who work with architects in having those studios built and seeing how they respond to that and what, how it works for them. And you would in a much more contained way get a sense of actually how does this work how does this not work, and I think you probably would get a better response out of those people.

RC: Could you perhaps give us a few names or contacts…

TA: Someone who wouldn't be bothered by a few university students…

CURATOR 1: I mean if you do it for Tate, it's much easier for Tate to give you those names but if you talk to someone like Antony Gormio…

KS: Who are the major suppliers to art museums and galleries?

CURATOR 1: No idea. Because in our instance, mostly what happens, you don't .. you work with lighting consultants. They do the…

RC: Like Arup?

CURATOR 1: Yeah, like LightWave. And they will source what is the best solution. Because in a way, I can only tell you what I need, what quality of light.

RC: What light consultants does this gallery usually use?

CURATOR 1: LightWave.

KS: To your knowledge, are there any art museums or galleries that are using LED's right now?

CURATOR 1: No

KS: Are there any government incentives that exist that encourage the use of LED lighting at all?

CURATOR 1: Not that I'm aware of.

KS: And do you anticipate a time at which LED lighting is mandated by law?

CURATOR 1: No, I mean I think what is a difficulty for all particularly public institutions is that you need to be very very cautious before you invest into technical innovation and that applies to anything like new media equipment because it outdates enormously quickly. I know LED is developing at an extraordinary pace at the moment and it gets used in architectural lighting… but primarily in my knowledge… to create moving facades because it offsets very well against darkness but not on the inside. So you need to know you need to have a pretty good track record before I think anybody would go there.

RC: You touched on a little bit earlier that there were different types of color temperature depending on the media. Could you give a good list of those?

CURATOR 1: Well it's generally; I mean you need to go back just simply to think about how these works were first made. So if you think about paintings, most painters paint in north light not direct sun so photites (??) daylight. So most paintings work best when the light is warmer, I mean not too warm but if you do artificial light it's warmer… painting in white is not white, it's warmer. If you look at black and white, so photograph y in particular, they're more pink colored because otherwise it looks yellow in the room. So you counteract whatever is in the work… so you need to have that degree of flexibility

RC: So generally, the lighting is meant to counteract how the art changes the color of the general room

CURATOR 1: The lighting is meant to counteract the fact that you are in a completely artificial environment. Basically galleries are totally artificial environments, like an aquarium, and in an ideal world, the light is invisible. And when it's visible, then it's gone badly wrong. If you're very aware that it's grey or pink, then…

RC: Then if you can see the actual color temperature of the light it's bad. So you try to… okay.

RC: So the 200 lux is really good for… so oil paintings are good for 200 lux and then …

CURATOR 1: No, the oil on the painting you usually allow, if it's a museum work, to have 250 lux. It looks fantastic if you can put 1000 on. That is when it looks great. So if you do

downstairs, if we can show a painter making new work, not sold yet, and conservationists say there's no reason why not to then 1000 lux is superb.

RC: But there's a huge battle there between trying to preserve the art … because that's a very large difference.

CURATOR 1: If you ever go back to Tate Modern, and you have access to ask them to turn one gallery very briefly 100 lux up and you would see what happens.

RC: Are most of your, it seems like there's a lot of natural light here. Is it mostly all of them open to the light, unfiltered?

CURATOR 1: No, the UV filters and they have there's no… they've got outside shutters so you can regulate the light of degree. But we're far less than if you build a museum now. But then nobody would probably build well I don't know if anyone would have open ceiling lights, I haven't been there for instance, the… has completely open ceilings, daylight.

RC: I'm just trying to see are there are lot of galleries that would be lit artificially here, or are there any in this actual building?

CURATOR 1: Yes, I mean they have light circuits you know to use spotlights and…

RC: But most of them are daylighted with added lights?

CURATOR 1: Yes

RC: Just trying to see if there would be any…

CURATOR 1: But this is more towards museums so it's quite important.

TA: I'm sorry if you already said this, but how long does the art usually stay here?

CURATOR 1: About 3 months.

RC: And you usually work with contemporary, alive artists?

CURATOR 1: It depends, I mean the next one is a complete museum exhibition that's totally controlled it will be 250 lux all the way through and it will be light…

RC: Shut the blinds, curtains…

CURATOR 1… people come for the show and they think it is so pretty and so beautiful the way the light is and say, yup, it is but unfortunately you can't have it like that.

All: Thank you.

APPENDIX F: QUESTIONS FOR LIGHTING SPECIALISTS

1. What are the advantages to LED lighting in an art gallery?

2. What are the disadvantages to LED lighting in an art gallery?

3. What barriers prevent museums from using LED lighting?

4. Are there other lighting technologies that are advancing as well? What are the advantages and disadvantages of those technologies?

5. We understand that although LED lights are more efficient than some other light sources in terms of lumens per watt, but do not always offer the same strength of lighting. According to Jeff Shaw at Arup Lighting, the best LEDs produce around 700 lumens, whereas galleries require 2,000 to 3,000 lumens. How long do you think it will take to develop LEDs that produce enough light for galleries?

6. Where do you see the LED industry advancing in the next several years?

7. Could LED lights fit in existing light fixtures? Would the position of the lights have to be adjusted due to the strength of LED lights in comparison to halogen and fluorescent lights?

8. One of the concerns of implementing LED lighting in an art museum is that it hinders the display of color from the artwork. What is being done to remedy the issues of LED lights being too blue or too cool?

9. According the head conservator at the Tate, the ideal color temperature for gallery lighting is 4,500 K. According to your website, you do not produce an LED that produces light at that level. What is being done to develop an LED that could meet the needs of museums like the Tate Modern?

10. What are the key attributes of the Artist XSM Series that distinguish it from other LEDs?

11. We understand that some wavelengths of blue that LED lights produce could be intense. How do you think that LED lighting in a museum would affect someone with a visual disability?

12. Where could we find more information on LED lighting?

13. Your document "LED usage in museums and art galleries" lists three museums or galleries that are using LED lighting: The Sunderland Museum and Winter Garden, Brooker Gallery at the Chicago Field Museum, and San Francisco MOMA (Museum Of Modern Art). Are there other museums, particularly in London, that are using LED lighting?

APPENDIX G: INTERVIEW WITH LIGHTING SPECIALISTS

LIGHTING SPECIALIST 1: Um and otherwise sustainability and that sort of thing. I mean, I've gathered what I've collected together here [which] focuses on the galleries, which are kind of not specifically addressed by BREEAM in the sense that they're still exempted from the [BREEAM lighting load]. Um overall project is aiming to be low energy at least as far as 20% less energy use and the other improvement plus getting the BREEAM … Um so um there's a, I think there's a few angles we can come at and LEDs is one of them, but that's one that we couldn't count on so in the project we have to see what …. We allow for …in galleries at the moment, which is lower than most. I think what I've got here are just some presentations we have done for the client on generally aspect of gallery lighting, which are, I wouldn't necessarily say unusual, but are on the more energy efficient end of things. We've got two [themes], part one is spotlights which we talk about when we talk about LEDs and the theme of daylight, use of daylight, and the use of fluorescent light… And both of these themes are themes that have been done in many museums in the past. Both these themes have been more done in museums in Europe than America…just because of different curatorial approaches

RC: We um talked to some curators … while we were still in the States, and they seemed very stuck on following through with the standards and not challenging them too much.

LIGHTING SPECIALIST 1: Right, exactly. Whereas in Europe you'll get museums where they haven't even installed track and its just daylight or fluorescent light in the space… That's not normal, but there is definitely a willingness, especially in modern art museums, to… just have ambient light in the space instead of spotlights … or that sort of thing…Um I'll probably start with what was actually most recent [planned] presentation we did just because this was an overview of the gallery lighting. And then there's a couple of specifics that I can go into a little more on … LEDs…So this a presentation we did … a couple of months ago. It's generally, I don't know how familiar you are with the layout of the building, but ah… in what called the switch house there are all galleries in this, level three, level four, level five…the gallery space it all different characters to it. Um this is a view actually done by the architect of the level three galleries and ah simply put, we've got lots of lighting track that we're proposing to put

fluorescent tubes in the track in a regular layout to provide that ambient light to the space, but of course you can also use track spotlighting if you need to … and so that is one of the themes is all these big gallery spaces where you're likely to have large works, you're likely to be aiming for the 200, 300 lux end of things on the walls instead of much lower levels. The ideal is to create … but obviously … they could switch them off, they could have dark spaces for medias… Have you gone much into curatorial standards about light levels and that sort of thing.

unknown person: No.

RC: No too much.

TA: We've got a basic understanding of how LED lighting works. That is pretty much the extent of our research.

LIGHTING SPECIALIST 1: Ok, I'll do it very simply …. I'm … going to really whiz through this, but this a presentation I did a while ago that is really describing sort the things you need to think about with gallery lighting … Um … So you know … you just create a black box for the art and when you make something [architecturally] spectacular – that's the different approaches to that … Its talking about when the [architecture] starts to distract from what you're actually trying to display or you can do both, having a fancy building on the outside and everything you need on the inside. Um this is briefly covering the difference between … the common American approach of we want black boxes, we want spotlights and quite a theatrical approach to lighting um highlighting individual objects, focusing in on them, um whereas what is often used in Europe, which is what I was describing to you before, its the side of much more ambient lighting spaces, you can compare works that are next to each other… and how if you're using daylight it does move toward that more European style … So there's various standards that obviously need to be used, um kind of rules of thumb how about much light [you can put] on the art, what quality of the light and distribution of the light and that sort of thing. And its really all about art conservation… A conservator, the people who are in charge of making sure the paintings last a long time, would prefer to keep them in a dark warehouse, as any light [actually does damage does damage the art]. So what you're trying to do is light them just low enough so that people can see them but not too much that the damage is accelerated. Um, and the fundamental is a convention which is, if … certain objects it does not really matter – if it's a stone sculpture or

metal, totally inorganic materials with no color or anything that can fade, then it does not really matter … If for oil paintings and reasonably robust medium sensitivity works of art, you tend to aim for somewhere between 150, 200 to 300 lux … 200 lux … is often the target. For very sensitive works of art which includes watercolors, textiles, photography, you tend to aim for 50 lux … And that's really the minimum level that you can light things so that people can still see them reasonably well and because those objects – the watercolors, textiles, photographs – are quite sensitive to light … and these are standards that are still used [all the time now] and LEDs can achieve this … And these slides… This is just an illustration of why. This is a painting by [Rosco] who did it for Harvard in the 60s and this is what it looked like in the 60s. There was … space in the Harvard with lots of daylight coming in. [Rosco] did use a lot of very organic pigments that were very sensitive to light and they closed the room for refurbishments in the 90s … So [after] 30 years this is now what the painting now looks like… This is a massive exaggeration because it is quite rare that this actually happens to a painting … The damage is cumulative so if you light something to 100 lux for ten hours, or 1000 lux for one hour the damage is pretty much the same. So it's useful with daylight to sometimes think about the cumulative effect … and if you go from average level to something else, sometimes it's low, sometimes it's high … cumulative … So sometimes daylight varies … This just talks about ah the fact that ultraviolet light [is particularly damaging] because … wavelength … ultraviolet … and its relative damage that that spectrum of light does to the artwork, so ultraviolet is particularly damaging and you don't actually need the ultraviolet light to see the artwork, so keep it away … And again with the LED side of things … which the ones that are being suggested … Um these talk about color temperature and what color of light is good for art whether … There's two measures of color of light … color appearance, and there's the color rendering index … so there's quite a subtle difference, so the color appearance is what color light looks like, [whether] it's got a warm feeling to it or a cool feeling to it, if it's more yellow or more blue … If you notice a place that has, if you notice an older office that has … fittings … ceiling … fluorescent tube … more often than not sometimes people have replace them wrong, and you'll see that actually some of the tubes are slightly [different colors than each other] … so the light isn't truly white, it is actually off-white … Your eye in a room where all of [the lights are a different color] will assume that its all white. There's a way of measuring this color appearance, which is called color temperature…The higher color temperature is a cooler source, and the lower color

temperature is a warmer source … So in here we have a probably light that is a color of about 3000 kelvin. Daylight in the normal daylight is … 5000, 6000 [lux] … You can buy fluorescent tubes that are a cool white or a [warm white] and the warm white tends to be around 3000 and the cool white tends to be around 4000 … um … So that's just a discussion of one aspect, and that's the easiest to describe and the easier to … You can have a look around and you see things, certain things you, you go to any museums that have a lot of daylight and spotlights and the spotlights usually look quite orange during the day because the daylight is a much cooler color and the contrast is [lots … warmer]… The second type, the second way we describe things, and this is crucial for when we have our discussion of LEDs, is color rendering. So this is not what color the art looks, this not what color light looks like, it's what color objects that are lit by it, or how well the … objects are. It's actually of the spectrum of light, it's a measure of how complete across the visible spectrum the light is [reflected naturally] … so if there's a bit of the spectrum missing, you're not going to see that part, and um you know, the example I use is … street lighting at night … [You cannot] really tell what colors cars are under it, that's because very efficient light sources are used for street lighting, but the color rendering properties of those lights are poor um … In the normal office environment, fluorescent lighting – sorry color rendering is measured up to 100 … it's like a percent … a hundred is perfect, rendering all spectrum sources of light … most fluorescent lighting that is used in normal applications is in the range of 80 to 85, which is seen as fine for more or less normal day to day things. Um for museums, we say that the color rendering must be over 90 so the color of the artwork is as close to the actual as possible … and ah this means [we use] an special type of fluorescent type of light which are actually less efficient than the normal fluorescent light, but … it means similarly with LEDs it leads to considerably … color rendering… in the daylight that you have to be careful with the glazing that you [don't] affect the color of the light coming in too much.

TA: What's the color rendering usually for LEDs. What number?

LIGHTING SPECIALIST 1: Most commercially available LEDs or white architectural lighting are in the similar range of fluorescents … in the range of the 80s. Some products, which I'll talk about in a minute are into the nineties now and that's where we start considering. Interestingly, the ones in the National Portrait Gallery …, are still the ones in the eighties. Um what's interesting there … if it's still in the same gallery where I saw it, first compare it to the adjacent

galleries … um with the [other gallery] there's some paintings which have quite a lot of red in them, which LEDs aren't very good at and they do look a bit flatter … there's actually some paintings which have quite a bit of blue in them, … [and blue is something] that LEDs are quite good at and actually they look very nice … So those are, those are actually the important things I wanted to mention to you. This presentation does go on to talk about other aspects of lighting. We want to avoid, obviously, not just … conservation but also get patches of [bright] light [on the painting and you cannot see it properly] um we want to make sure it's uniformly lit … um … You want to put the light in the right place. If you imagine a picture with a glass frame, if you put the spotlight too far away, then when you're looking you can see the reflection of the spotlight. If you put the stoplight to close then actually the shadow of the shadow will cover the top part of the painting. So there's sort of an optimum distance where spotlight pictures go …

RC: …when we visited the Tate Britain, we realized that a lot of their artwork in the older galleries … they had a lot of glare on the paintings um was that because – and we noticed one of the biggest differences was in one of their [older] galleries there was open-bulb fluorescent lighting or spotlighting in [some cases] while the newer part incorporated some natural light and more like filtered out the fluorescent effect?

LIGHTING SPECIALIST 1: Yeah, I mean I think there's about when you're seeing a reflection of a source of light I think some of the older galleries … big skylights… and you're seeing a reflection of those, whereas new galleries are designed so as the skylights don't really … [get in the way]. In terms of the spotlighting and that sort of thing it should be …

unknown person: …

LIGHTING SPECIALIST 1: Yeah, I mean it's in the gallery I showed you and I'll go back to it in bit you will potentially have reflections from fluorescent tubes on paintings … once you build the space … so at the same time there are big tall spaces and hopefully most of the art was at a level where it … the angles … As I'm going to talk about daylight briefly … this [is a brief introduction to daylight as well]. There's obvious reasons why we use daylight, partly sustainability, it's a very low energy source of light … um … but also because it has excellent color properties it's [what we base it all on] so it's ah full spectrum and ah um so it's really nice quality of light as well, [which is why we want to use it] ... um there is a lot of UV in daylight,

that's what this graph shows [so you have to make sure the windows filter it out … um what this shows as well, what this plot shows – this is probably in the UK … but it could be somewhere in America - … but um each dot on that graph is one hour in the year, and it's saying what light level outside it is during that hour of the year. So generally it's a bit lower in the winter months, and it's a bit higher in the summer months, there's a lot of dots lower down when it's nearly light or dawn or dusk basically, but ah in this particular case you can't really see some of the dots are red some of the dots are blue. The blue dots all happen when the museum's probably closed, whereas the red dots happen when … open. Um but this just shows the variation [in heat in the mid summer], you can go from 100,000 lux or 10,000 foot-candles outside to nothing within a day, so it varies a great deal, which is one of the challenges of daylighting going back to trying to just have 200 lux on the wall all the time … um so again I'm not going to talk about lots … of the museum … there's lots of different ways of controlling daylight um … current Tate Modern … which they're going to use... There's two broad approaches, you can either … try to get 200 lux on the wall all the time, in which case you're going to have a system that reacts when it's bright outside it closes inlets and when it's not bright outside it opens them, but they tend to be very complicated, lots of moving parts, you install them in places like Tate Modern, and they stop using them. The other approach is [what we say a] passive approach, where you have a fixed shading system which you usually block or direct [sunlight around] because you just let in light from the sky-hole and reflect it [sunlight maybe you know] and that produces a variability by a significant amount because the big variations … um and then you filter it to a certain level within the space that gets you within a range where …. [average] …

RC: Um just out of curiosity, how much do you know about the sky lighting …

LIGHTING SPECIALIST 1: I was going to go into that in a moment.

RC: … but we might be able to tie it into the innovation part later …

LIGHTING SPECIALIST 1: Yeah, exactly I'll show you that … So that's just a quick introduction to day-lighting in museums, [lighting] in museums, sorry. Um if we go back to this … this does show you what happens in those [parts] um … So this is – just quickly – this is level three, this is um the approach here is to try and mainly use the fluorescent which is [a] lower energy approach. If you are just lighting certain artworks in the space, and if you want a specific

level of light – 50 lux or a hundred – it is probably still ... to use halogen spotlights because they can only light in the area [of the wall surface] that needs the light and nothing else will get lit. If you take [this] approach of filling the room with light, which is often done with spotlights … and certainly this is much more efficient um we did a quick study … because this is one of the potential criticisms leveled at us … where if you are lighting the walls to an even level of 200 lux using fluorescent light or doing it using a number of spotlights then we use 11 watts per square meter with fluorescents and 30 watts per square meter with halogen spotlights, so you know one argument is that by using fluorescents we could reduce energy usage [to] a third – it's not that simple …

RC: You did say um 35 watts per square meter. Is that like general a rule or is that what Tate is trying to get to or …?

LIGHTING SPECIALIST 1: I mean that's a rule in that ah you've got to design certain elements like the air conditioning system, need to know [what the temperature increase will be from the lights] … um so it is a design parameter. In theory, they shouldn't go over it in the spaces … With track lighting … given that we're almost certainly using LED spotlights …

RC: Um is in, ah what's like another standard to museums around …

LIGHTING SPECIALIST 1: It's difficult to say, I mean ten years ago you were probably … [brighter] … I mean it's it's it's gone down a lot. The previous museum I did we were at 40, 45 something like that … um so there you go, so here we're using special high color rendering fluorescent light [like those I was mentioning before] which the payoff is that you get about at third less light out of the same fluorescent tube as a result of adding those extra wavelengths … spectrum … that still makes the fluorescent tube more energy efficient itself … and actually there are LEDs that … so that's them … the level four galleries … are likely to have more of the more sensitive 50 lux objects that I mentioned before … so the idea here is just tracking spotlights … and then for the level five gallery, so it's the day-lit spaces … architects' rendering of the space, basically a glowing ceiling. It's a stretched membrane, sort of a white fabric um … actually over in the new building, the tower that's across here, so we couldn't actually daylight this gallery, so we're only day-lighting this gallery, but inside they look the same, this gallery is going to have the same sort of … ceiling but with fluorescent lighting, this one has day-light or

fluorescent lighting … um … this is a section through, so this is the stretched fabric ceiling, stretch membrane. Barrisol is the probable material we will use … which is a brand name for it, they do these translucent … materials. So that's this layer, then inside you've got [the frame with fluorescent lighting on it] that will light the ceiling at night … and daylight … we ignore… This is the actual glass we place in the skylight ahum … this is where the barrier is, this is where the UV is filtered … glass … and on the roof we mount this grid which is like this and um this is these slanted surfaces are more open towards the north than the south and the angles that are blocked just allows in as much daylight from the sky as possible, [which] blocks direct sunlight from getting into the system … produces a variation … of light … diffuse daylight instead of the direct sunlight … Um what we've said is for exhibitions where they really don't mind high light levels …[not sensitive works] … they can actually open these grids on the roof … and that way a lot more daylight, the sun will get into the … and it will be a much brighter space – maybe for the exhibition that's fine, then most exhibitions they will keep it closed and ah … much more limited amounts of … um but being a white diffusing material, even if you've got sunlight coming in … the light in the gallery space will create [a decent spread] … it's a bit like in the existing Tate Modern… that's the system. Um what we have here is … these are similar charts to what I showed you before about the variation, but these are for what's happening inside so we factored in how much daylight actually gets in the space. This is sort of our condition where the roof is open, [where the … is open], and this is our condition where the screen on the roof is closed, so you can see that, I mean that this is about 400 I think, lux and this is what is on the walls on average [and] so you can see you get a much more limited range of light levels in there when the [screen] on the roof is closed and this you know, on average you're getting around 200 lux, which is [deemed acceptable for conservation] um and these numbers show that in different seasons, but ah you know in this condition in summer you've got a maximum level of 400 lux and on average … you'll get 240 lux on the walls … In the other seasons it's a bit less and then overall … cumulative exposure … range… so um that's the approach you should take, the idea being that without allowing such bright levels that could damage that artwork we keep it within in a manageable range but we try and maximize the amount of time we could potentially just have daylight in the gallery…

RC: There's a question on this. Um… has this idea been used before?

LIGHTING SPECIALIST 1: Yeah, I mean this sort of approach has been used in a lot of museums … The Tate is um you know they're worried about, once you bring daylight into a gallery you do somewhat reduce the flexibility of it because you can't – unless you have a [facility to block it all off] … unless you have that facility you can't … [display extensive different artworks in the gallery], you can't do video art, exhibitions that … no light …so it reduces the flexibility and so the Tate are wanting to make sure they … [temporary spaces] … partly why one only one gallery out of … this is one sixth the new gallery space – is day-lit and it's partly why we needed a system that keeps it within very manageable ranges. There's other museums that you go to … there more flexibility … There's countless different solutions for control of daylight … It tends to come in through the roof mostly because it's easy to distribute evenly in the space um and … vary … controls … and it's a more classic approach. If we have more time [I can show you some other things we've done]…I'll maybe give you an overview afterwards … Um so that's the day-lighting approach generally, I mean other examples are, well we try to do … with the original Tate Modern which as I said isn't used quite as it was intended, although right now in the galleries … those windows … the high level, there's still daylight coming in all they've done is they've blocked off about 2/3 of the window because they've decided that the right amount of daylight to come is a window that's about 2/3 blocked off um and there is a simple system where again the light coming in is diffused by the glass so you don't actually get sunlight on the wall and its in a manageable range… Quite recently, last year there's a new … and that's very … Where are you guys from?

RC: Massachusetts.

LIGHTING SPECIALIST 1: The ICA Boston was one of ours as well… I think that's [got the top open]? Bear with me a second.

TA: Um we talked with the project manager at the Museum of Fine Arts in Boston as well and um …

LIGHTING SPECIALIST 1: Ok

TA: when we asked him about lighting, one of the first things he said was how day-lighting, day-lighting was a huge "No-no" to use his words.

LIGHTING SPECIALIST 1: Yes, a lot of people still say that. This is day-lit, that's the ICA Boston, and it's a quite similar approach to what we're going to be doing in the Tate … I didn't personally work on this… I don't know exactly what's above this, but this is fundamentally a diffused ceiling above which they mounted moving controls in some way to produce the variation. Um it's probably a reaction to … there's still feeling … these are the reasons I told you just now about the Tate not wanting to go … its difficult to control, it reduces somewhat the flexibility of how you use the spaces, and again it does go back to curatorial norms, some spaces if they're only going to have … even if you get it down to a level to which you can do it is still … And um you've lit the whole space to 50 lux … where as in those sort of exhibitions. Yes, having the rooms… spotlighting the painting themselves… contrast… well lit. there's merits to that approach still… with all of the curators still think even at the higher levels…day's too uneven, too unpredictable... people worry about the UV content although you know about that.. so yeah, the ICA boston is a place where you guys… see the Tate approach in effect. A couple places in New York which we worked on, like the Morgan Library in New York which … this Morgan library… good example that has this system… in one direction you can see the sky and the other direction you cant… blocking the sunlight. And that's used in the morgan library… in lots of spaces.

RC: Does it matter which direction it blocks light from? Or is it to just block half the light?

LIGHTING SPECIALIST 1: No, it's to block the sun. so if it's somewhere in the northern hemisphere, it will block this half… It's not that simple… in the summer the sun is quite rather northeast and northwest… rising and setting. So just blocking the south half is… quite a lot of sun coming in from the north… so that's why it's a two-way system… north blocking it from the south… blocking as well… different parts of the world… wherever you are in the world, the angles you need to block are different… um should we talk about LED's? What we've got here is a little presentation that we've done for a few clients… including the Tate… about LED's for gallery lighting. And why they haven't been appropriate until now and where we are in getting…

RC: …How long…?

LIGHTING SPECIALIST 1: This year I would say. We started on the Tate… we started working… Tate Modern early last year… um, and even then we… not sure… pretty certain that

by the Tate opens that it will be… I think pretty much everything on this list… has been resolved… um, the one thing that isn't quite really there is the… so the LED products that are resolved from the other issues… To replace, you know they can now replace 50 watt halogen fixtures, 100 watts, not yet. And in these big tall gallery spaces you probably need that amount of light… so it's a case where they've resolved a lot of the technical issues but we just need to wait for them to get a bit more… And every year there's a bit more… every few months…so that's the only thing obvious right now I think… we just need a bit more… so these are the main issues to consider. So this is why it's good that I just told you about color… color rendering's a big deal, also the consistency of temperature. So as I was trying to describe to you, you get different color appearances of light sources, and one thing white LED's haven't been that good at is being very consistent. So, um… this is an actual installation of LED, it's uh where each one is actually looks a slightly different color. And that's a big issue that arose with spotlights in gallery space with each one as a slightly different color. And that is also to do with the way they package LED's, um, what they do… this is where… color appearance… um, so you've got this big color spectrum, this is white light, or what we call white light… these are the different color temperatures that I was talking about before… um, and again in this illustration… high temperatures… very blue… it's kind of, the measure is if you heat up an object, it starts to glow orange… um, so if you take the certain points on this curve, how would you, there's sort of a tolerance at which sources will look the same. And basically what we're saying is, from the search, if you're within this ellipse so if you're package is within here or here or here or here, somewhere within this ellipse, well this is what you're aiming for but if you're somewhere within this chart, then you might notice the difference… one here and one here… so that's based on sort of the search. Um, lets uh, that's basically saying the same thing, uh now when they manufacture LEDs they can't get the same, what they do is in the process, is as the LED's come out, they test what color they are and they bin them, they put them in different bins, based on where they are. And more finally they bin them with them as close as they are together… um, so… represents the binning process. Each of these would be a (good?) LED… and this intensity… Well this is a two-step ellipse in which … and this is the best LED… as it were. So you can have one this color and one in this color… so that's the problem with LED's in the past. So, currently, the manufacturer does two things. One, they're looking at the weight of getting those bins (packaged?) to get them all in their direction. The other, is what we talked about here,

I don't know if you know… Xicato, that's X-I-C-A-T-O. Terrible man, they're making LED units to sell to manufacturers… um, and what they're doing is instead of the normal white LEDs is blue LED… while adding phosphors to… so they used the blue LED in some… what this company Xicato is doing, is instead of having the phosphors in the LED, they just used the… um, and then they have a separate unit of a phosphorous tank… and they got 7 or 8 different… codes… so when they get their LEDs… the results is that now… that can go… ellipse range away… so that's been one problem in the past and that how its currently being resolved. Another problem, I think we've already talked about this is color rendering index um… daylights… halogen lights and incandescent lights … as I said, the typical fluorescent lighting…cheap as far as lighting… and um, the high color rendering… some galleries but not the Tate… design for the level 5 galleries in Tate will be 96… um, so the problem with LEDs is again, the … white LEDs from the… um, again what's happened now is the Xicato product has improved… the way they manufacture it. What this is showing is the way color rendering index is actually measured and what they do to measure color rendering is that there's all these records of pastel colors and strong colors and you're looking at the reflectance… light reflecting the tunnels… so standard LED has this profile on the chart… its okay for some of these but its awful in level 9… yellows and the blues… um the Xicato… so again, now some of the manufacturers are coming out with LED… slightly UV, typically some of the earlier LEDs have more UV content, now much lower… so you know, UV's not a problem. Efficacy is the way we measure efficiency, um, a single unit of light is called a lum and lux is lumens per square meter… so we measure the efficiency of certain sources of lumens per watt… so power in, lumens out. Currently… 30 lumens per watt which is better than halogen…most halogen is 19… fluorescent light is… color rendering is about 70 meters per watt standard 100 meters per watt… and so we're still, even now with LEDs we're still at the lower end of this… LEDs is sending all the light in one direction… by its nature you will lose more light from the fluorescent surface before it reaches anywhere else, more than LEDs, so there's this, the overall efficiency of the lighting fixture with the LED in it has improved… so anyway, the point here is currently 700 lumens… we need for spotlights in galleries to have 2000 3000 spotlight in galleries… so we expect by the time Tate opens, LED… Good things about LEDs, obviously the life is good… I don't know if you got into this, but um halogens are also used… galleries until now… will last about 3000 to 5000 hours, there's 8000 hours in a year, so if they're using them for 12 hours a day… they're still

changing their halogens at least once a year… the difference with LEDs, um is um this 3000 to 5000 hours is statistically half… the point is, that the LEDs are useful by… many more thousand levels so 10 times the level so maybe you don't have to change them every year rather than every year, so that's a good part about LEDs, the bad part is that they can get expensive and even though they last longer… the payback, there is a payback but it's not 6 months, its years… you know if you assume that you're saving… the intent of it is 5-10 years… some institutions are very happy about that… cost will come down in time…

TA: so LED, you can't really fit an LED lighting into an existing fixture, you have to go and get…

LIGHTING SPECIALIST 1: yeah, yeah

TA: yeah, that's what we thought

LIGHTING SPECIALIST 1: one of the other things… you know, the manufacturers decided because LEDs last so long, you know 10 years… they decided… and even the ones that are at the Portrait Gallery… LED there… If one goes wrong you don't want to throw away the whole fixture…..Factory…Well, they're making the MR-16, which is this kind of reflector. They're making LED versions of it that no one else has even started to talk about yet.

RC:…Money….?

LIGHTING SPECIALIST 1: Well, that's why I think the making of these modules is standardized. And they can put it inside the fixture and take it out…We will make the lighting scheme work. Even though they have the policy, it has become less of a worry. I think it's the wrong thing to go down there…you know light sources that cost a few thousand watt. The other thing to do would be to speak to the manufacturers. Big manufacturers are like…

AN: A tax cut, or some sort of incentive? To push, push back?

LIGHTING SPECIALIST 1: That last ones different. I don't know, I think its just the rule of the image. And I think the incentives are in there in terms of releasing mighty energy. We look at legislation and we say that after we build it, its about the efficiency. Even now, most commercial buildings on average, we have to get forty five new limits….fixtured, not just the resource. So

you can use less efficient….Even for a residential, things would come for something like…. And there's a certain proportion of the resources in your….me and my house in a residential government, there's a certain proportion of light sources…Quite a bit of legislation…Seems like the fact that…In Europe, and in other countries, they're beginning to ban waste ….and its pushing people that way….Just Quickly, talk to the lighting fixture manufacturer. …outside

RC: How much of the floor space should be accounted?

LIGHTING SPECIALIST 1: Only the galleries...Yeah, basically. The office….The Tate….is still a much more efficient….Its still much better. And we will probably use the west front… The Circulation areas…That does cover a fair amount of the Tate.

TA: ….

LIGHTING SPECIALIST 1: No, basically there are parts of the Tate that are being redone as part of this project. Again, those are the learning areas…serve as a bridge…An office annex…So in those particular dimensions…as to whether they decide to use spotlights…They probably will replace eventually….So not yet, but at some point in the itinerary.

TA: The way I understand the LED lighting is that different, it's a like a semi-conductor that you're running electrons through to conduct light…something like that….So part of the problem with the light is that it doesn't emit the right wavelength. If you use different conductors of LED light….what's the problem with that?

LIGHTING SPECIALIST 1: … You could use a red one, a green one, a blue one…the problem with that is….it's a bit unusual…not a bad thing...electrical, with three sources next to it…and the angle might slightly differ with your sources…and mainly…you get to umm…it's the spectrum as well….A red array, a green array, across the spectrum. It wouldn't be good …that's not to say…I think we will realize its within the light as well…phosphorus…when excited…how you mix the phosphor and what color comes out of it…and mix the colors together and you can get a much more even spectrum. These are spectral color distributions and these wavelengths, and this is what you get when you mix and get the RGB…the four spikes and an even distribution…I mean it's not flat….That just shows you a little bit about that sort of thing. This is

the halogenic lamp….I'll show you the curve….This is actually a blue LED… and then this red line… so there you go, I'll send you some of these things

RC: Thank You

APPENDIX H: INTERVIEW WITH LIGHTING SPECIALIST 2

LIGHTING SPECIALIST 2: So the first question is what are the advantages of LEDs? To my opinion it's very straightforward, it's cost of ownership. So compared with halogen you get energy saving[s] and lower maintenance costs. And then the disadvantages – the initial costs, at least compared to halogen are higher. So if you look at let's say a payback, take it over the life of the installation of course the costs are lower … typically a payback of 2 years is easily proven, but the initial costs nevertheless are higher compared to halogen. Now I can see from some of the questions further down in the list, you expect[s] the disadvantages is gaps in the spectrum. So you don't get the full palette of colors, and secondly, the light at the blue end of the spectrum, around 450 nanometers, or 400 to 450 nanometers, affecting yellow pigments and there was a letter from Dale Kronkright about this, which you probably know of, from the Georgia O'Keeffe Museum. So here LEDs have improved such that I'll say that's it's not a disadvantage anymore. Instead of using single phosphors, dual phosphors are used over [?]. An with attention to the right phosphors you can have a complete distribution so not gaps in the spectrum, and secondly, you can minimize, you should not cut out completely the blue wavelengths, or you would have a problem with the other, with the gamma issue, but you can lower it such that you don't get this issue with the fading of yellow pigments. So actually, the disadvantages of LEDs I would say basically hinge on initial costs at the moment, and secondly depending on the – LED technology is not as mature as some other technologies. So maybe there's not such complete a range of luminaire manufacturers, for example I'm just thinking about. Maybe you could say, certain technologies – for example if you have a remote phosphor technology, having a narrow beam width is difficult without a big reflector. But these are very detailed points now. I would say the most important one is initial cost. OK?

TA: One concern that a conservator did have was he didn't think LED lighting would be very good for ambient lighting, he thought as far as spotlighting it would be an effective technique, but he wouldn't um –

LIGHTING SPECIALIST 2: I guess what's behind that comment it the lumen package from individual LED modules. So if you take our module, for example, the Xicato spot module. It

goes up to 1000 lux – lumens I mean – and by the end of this year it will be 2000 lumens. OK, from a 5 foot fluorescent lamp you get 5 to 6 thousand lumens. So, it's not that you cannot do general lighting, but you would need more luminaires to do it, or uneconomic space to height ratio, which is why – precisely - this reason, that in the market, LEDs have started off for accented decorative lighting, because that's what you can do effectively and economically with the current lumen packages. For general lighting you start either having to add together lots of LED modules together inside the luminaire, in which case the luminaire is expensive, or having lots of luminaires in close space to height ratio. It's not so economic yet. Did I answer you question?

TA: Yes, that answers it.

LIGHTING SPECIALIST 2: So actually that leads right on to the next point where you say "Where do you see the LED industry advancing in the next several years?" And I see it going into different application areas. So beyond accent and decorative towards general lighting for example. Ultimately beyond indoor lighting to outdoor lighting as well. It will start off [amenity] lighting, minor roads, residential areas, but eventually it will be other outdoor areas. So it's … as the efficacy of LEDs increases, as the power per module or area, the flux density, if you want to put it that way, increases, then it will open up more application areas. OK, by the way, I see I've missed out a question, you asked about other lighting technologies – of course they're advancing as well. If you look at compact metal halide, the efficacies are improving, you'll get to maybe 130 lumens per watt or something. Secondly, the quality of light, the [??? 6:43] the rendition of deep reds is getting better, thirdly the ability to dim the lamps without color change is improving. It's an exciting to be in the lighting industry, with this sort of internal competition among the lamp types. Ultimately, it makes sense, markets don't go backward. I think LEDs will take over many areas. Just the inherent robustness of them, there's no arc tube to leak or filament to break.

So actually I think I answered this one… You say that LED lights are more efficient. Actually, it's not true, it will become true but at the moment they're more efficient that halogen. They are not more efficient than compact metal halide or compact fluorescent, though you must look at it

in its totality. In a luminaire, because the light emitting area is smaller than let's say a compact fluorescent lamp, you can have more efficient luminaries, so don't look just at the lamp efficacy look at the whole luminaire efficiency …

In terms of could they fit existing light fixtures, luminaires you mean, the answer is … there are retrofit lamps on the market. For example, you take out a [dichroic], or one of these twist and lock [main] voltage halogen, and put the LED source in, but always it will be limited in lumen [package] because with LEDs there's hardly any infrared output, but there is convected heat you have to deal with, so you need a heat sink. And if you're trying to incorporate a heatsink in a given envelope because you want to [???] some existing source, there's always going to be a compromise, so to use LEDs at their best and to get as much light out of them as possible you need to either make an adaptation of the luminare or start again to deal with the heatsinking.

…

TA: You're definitely hitting all the point we need.

LIGHTING SPECIALIST 2: … "One of the concerns of implementing LED lighting in an art museum is that it hinders the display of color from the artwork." … I think I already answered that. Let's say there's always a compromise in the whole of lighting. It's not just LEDs. If you improve the color rendering, the tradeoff is that the efficacy will go down. And so with LEDs, LED modules if you have a ideal one for museum lighting or for gallery lighting, it has a complete spectrum. If it has a complete spectrum, it's probably 20% less efficient. So I'm not saying one is better than the other, but for certain types of lighting, let's say efficiency is most important, and you don't need such precise color rendering, and for other areas it's the other way around.

TA: You said the phosphors were the way they were addressing the –

LIGHTING SPECIALIST 2: Let's say with a typical … LED module you have InGaN, a blue LED and the blue light is converted to white light by a phosphor, a yellow phosphor. To

improve color rendering you have a mix of phosphors, typically a yellow, a YAG, and a red phosphor. If the higher the color rendering, normally you increase the amount of the red phosphor, which is around 650 nanometers, or above. But the red phosphor is less efficient than the yellow phosphor. Do you see my point? So you fill out the spectrum, you have perfect color rendering for galleries and what have you, but because you're using all the red phosphor, the efficacy would go down. It's a tradeoff – this is physics. Ha ha! You can't have both.

Now I wasn't quite certain by what you meant by this question: "We understand some wavelengths of blue could be intense…" I mean certainly with our modules we comply with IC 62471, which is the photo-biological one. It's true if you have too intense blue wavelengths you can have retinal damage and this sort of thing, but irrespective of its [lights ??? 12:12] you should comply with these standards. I would say also watch out because this is a very involved topic. For example with older people, because … as you get older the eye changes, and I'm not a expert here, but let's say it's due to the thickening or the yellowing of the lens and this sort of thing. And the blue wavelengths don't get through so much, and so for older people they do need more of the blue wavelengths. So its again kind of a tradeoff, you have too much blue wavelengths, it damages the retina, not enough it is going to be an issue for older people.

Then you say "Do government incentives exist that encourage the use of LED lighting?" The answer is certainly yes. There's the energy savings trust, for example, administer an incentive that if you use LED lighting you don't pay capital gains tax or something like this. I'm not an expert in this area, but I do know they exist. I do not anticipate that ever it will be mandated that LED lighting specifically is … I see it the other way around, [to a certain extent] that incandescent lamps are being banned, and maybe halogen lamps, I don't know. But … I can hardly imagine there'd by a government mandate you must install LEDs.

So [LIGHTING SPECIALIST 1] gave you a copy of the article that I wrote did he? So in there you'll see the Museum of Modern Art in San Francisco, the Chicago Field Museum, a few in this country up in Sunderland. They're the only ones I know of. Manchester Art Gallery is looking at using LEDs now, but it's not installed yet. In terms of finding out more about LED lighting … there's the lighting institutions like the BLDA, LIF the Lighting Industry Federation, IALD. I

think you should go to these kind of independent … I mean you can look at the Xicato website, that would be a funny answer, then of course it's – I talk about Xicato more, or if you go to Cree, they'll talk about Cree, or Philips, Philips and so on. So I would go to independent places like the BLDA, IALD, LIF, IES, Society of Light and Lighting. Go to these type of places for independent knowledge.

Ok, so I've raced through them a little bit, but what questions for me now?

TA: …It's a question with color temperature, according to the head conservator at the Tate, the ideal color temperature for gallery lighting is 4,500 K. And –

LIGHTING SPECIALIST 2: Are you sure … I hear all kind of different answers on this. Some say 3,000 Kelvin, some say daylight, they want it 5,000 Kelvin. I gave up a long time ago that there's a standard this is museums, this is the color temperature.

TA: So opinions vary on color temperature. Usually?

LIGHTING SPECIALIST 2: Which is … an advantage of using a separated phosphor, by the way. Which you can mix the phosphors to get different color temperatures.

TA: I think that's pretty much everything.

AN: One question that I had is: Do you anticipate a time when you would make LEDs with a higher color temperature, like around 5,000 or so?

LIGHTING SPECIALIST 2: Now. To go back in history to start with, let's say high brightness LEDs, so when LEDs first started entering the lighting market in the late 1990s. What triggered this was the invention of the InGaN LED, the blue LED, and to start with it just had a single phosphor on and the norm was 5,000 Kelvin, if not 7,000 Kelvin. The progress is getting away from that towards the warmer color temperatures, the 3,000 Kelvin, even 2,700, like an incandescent lamp. But if you still wanted the 5,000 Kelvin that was already there … Personally

I see the way ahead is with separated phosphors. So you have the [blue pump ??? 18:04] underneath, then the separated phosphor, and by mixing the phosphors, you can have any color temperature. What our company does is [have standards] 2,700 Kelvin, like incandescent, 3,000 Kelvin like halogen, and 4,000 Kelvin … like the type of fluorescent lights that you see in offices. I think these are the main ones. To make a 5,000 Kelvin is of course possible – this is not a technical question, this is a commercial question. Every museum job I have done so far has not wanted 5,000 Kelvin … 3,000 Kelvin is the one that has been used so far, in the museums I've quoted. I also find it a bit strange … It's quite common to have daylight in an art gallery from an atrium or a skylight or something, and then spotlights around it for accenting individual works of art or sculptures or what have you. And for me it makes more sense that you have less of a mismatch as possible in the color temperatures of daylight compared to the – so I think it's strange, but all I can do is pass on my experience. Every gallery I've wanted so far has wanted 3,000 Kelvin.

TA: His opinion on daylighting is he'd rather not use it, even though he's a conservator at Tate Britain - well actually all the Tates – and they are using daylighting, he wishes they didn't. And so he was saying for his ideal gallery he would have 4,500 K. So I mean his opinion seems a little different from some of the other ones we found, as well…

LIGHTING SPECIALIST 2: There's another school of thought which is that it's preposterous to say one answer for an art gallery in terms of the color temperature. But for example, if you're displaying old Dutch [marshes ??? 20:20], Rembrandt and Vermeer and this sort of thing, if they were painted by candlelight, then you would want the color temperature to be 2,500 Kelvin or something because it's fitting the school of art that's being displayed. Then I can imagine if its impressionist art which was painted outside, then indeed you'd want to see it in daylight. But take care, I've now given you a personal opinion rather than a –

TA: That's fine.

LIGHTING SPECIALIST 2: I also think as a complete aside - and not just relevant to museums – it's impossible to mimic daylight with artificial lighting. A) it changes, daylight changes all

the time, you can't just play around with the color temperature to get the daylight. You've got [a range] that's to do with the movement, changes. It's a very hard thing to deal with, artificial light. If you're calling – making color temperature 5,000 Kelvin or 6,500 and saying it's daylight, it's one aspect of daylight, only it's not the complete story.

TA: So as far as the Tate Modern, what kind of color temperature do you think with contemporary art –

LIGHTING SPECIALIST 2: My gut reaction is a higher color temperature. For the reasons I've just given you. If it was go to the Rembrandt room in the National Galley, I would expect a warmer color temperature. If I'm looking at that Jackson Pollock thing or – which I love by the way – I want a cooler color temperature. This is a very personal, thing.

TA: …But, seeing as you're an expert in the lighting field, your personal opinion does matter.

LIGHTING SPECIALIST 2: Thank you.

APPENDIX I: SUMMATIVE TEAM ASSESSMENT

Student A

Student A showed efforts to improve his writing style. Edits were conducted frequently, along with multiple rewrites. Student A also put in effort to stay more focused throughout the work day. Student A also tried to allow others the opportunity to talk more often.
Three areas that Student A contributed in outside of authorship are:

1. Conducted interviews
2. Transcribed one interview
3. Offered input in team meetings

This student showed a consistent effort to become less distracted during work days. They edited other's papers very well.

1. Conducted interviews with Lighting Specialist 2 and BREEAM Assessor
2. Facilitated weekly meetings with advisors and sponsor

Student A made a good effort to address his areas for improvement. They allowed others to talk more in the meetings, was distracted less often, and worked diligently on improving his writing.

1. Conducted interviews – Student A was willing put his own report aside to conduct an interview that had no immediate benefit to him
2. Transcribed an interview
3. Provided highly constructive feedback on the group's written work

Student A addressed the areas of weakness on his formative group assessments extremely well. One issue was that they were easily distracted by the internet early on. They solved this problem by never allowing themselves to have access to the internet. Overall, they were an extremely productive member to the group.

1. Conducted interviews
2. Transcribed interview
3. Added intellectually to all papers

Student B

Student B showed significant improvement in his grammar and spelling. They also showed efforts to take a lesser speaking role during team meetings.

Three areas that Student B contributed in outside of authorship are:

1. Offered input during team meetings
2. Conducted interviews
3. Conducted extensive and crucial background research about BREEAM

This student tried to allow others to speak more during meetings. Their writing style improved over the course of the term.

1. Conducted interviews with BREEAM Assessor, Lighting Specialist 2, and Conservator 1
2. Facilitated weekly meetings with advisors and sponsor

Student B addressed his areas for improvement well. They let others in the group talk more and he offered to take notes at the meetings. Their spelling and writing improved immeasurably.

1. Conducted interviews with an affable and conversational style
2. Ran meetings effectively – Student B had a good understanding of all aspects of the project and was able to communicate them to others well.
3. Helped direct the group with insight on how to best spend the group's time

Student B addressed most of his areas of weakness from the formative group assessment. It was determined early on that they were too aggressive in meetings. They therefore attempted to take more backset roles. Most occasions, however, they still were over barring in meetings. Another issue which they worked greatly on was his writing skills. They worked diligently to improve this skill throughout the term.

1. Analyzed BREEAM manuals
2. Conducted interviews

Student C

Student C showed efforts in improving his writing style. They extensively edited their writing so that it was of a higher quality. They also tried to assert themselves into a larger speaking role during meetings. Three areas that Student C contributed in outside of authorship are:

1. Consistently took notes from meetings and interviews
2. Transcribed multiple interviews
3. Conducted extensive and crucial research about LED lighting

This student took an effort to speak more during meetings. They showed a consistent effort to change writing style.

1. Took minutes for weekly meetings with advisors and sponsor
2. Transcribed interviews

Student C made some progress on his feedback from the formative assessments. They contributed more to group meetings and tried to make their writing more concise and less verbose. They did not succeed at becoming more outspoken in the day-to-day activities of the group.

1. Transcribed interviews
2. Helped arrange interviews

Student C addressed the areas of weakness on their formative group assessment extremely well. It was decided early on that they did not participate enough in group meetings. They addressed this issue by volunteering to be facilitator on multiple occasions.

1. Transcribed multiple interviews
2. Took the majority of minutes and notes for the group.
3. Added intellectually to all papers

Student D

Student D was spoken to on several occasions concerning their presence in the group. After speaking to them, they would show efforts towards improvement. These efforts tended to fade and problems with contribution would resurface. Three areas that Student D contributed in outside of authorship are:

1. Formatted IQP
2. Transcribed interviews
3. Made phone calls to set up interviews

This student worked on becoming more involved with group and strived to take on more responsibility within the group.

1. Transcribed interviews
2. Formatted IQP Paper

Student D made some progress on their feedback from the formative assessments. They rejoined the group in the common room after a hiatus. They began to take more initiative, but could have taken more over the duration of the term. Their punctuality improved for a while, but then seemed to worsen; overall, it was inconsistent.

1. Transcribed interviews
2. Provided formatting and editing support
3. Arranged interviews – This was a tough job as few museums were interested in helping the team.

Student D struggled to achieve the areas of improvement on their formative team assessment. One issue was constantly late to work. Even after both formative assessments, there were still several occasions where they needed to be woken up to come to work. Also they still seemed unwilling to work out side or above scheduled work times. They did however start to take more self directed work near the end of the project. The work also became more on time and of a higher quality.

1. Transcribed interviews
2. Formatted IQP and Appendixes

Group Assessment

The group did well in addressing the major areas for improvement from the formative team assessments. The first area was our writing. The group lacked sufficient editing early on in the process. By the end the group advanced to reading every document multiple times by different people to guarantee a better writing style. Second, at the start of the term we believed speaking roles were uneven. We addressed this by giving the most out spoken people passive roles, like taking notes. Third, was the group's work ethic. Early on it was noted that the group was easily distracted at IES. This area was addressed by members reminding each other to stay on focus. Lastly, the group lacked improvement in one area. This area was preparing before meetings with the advisors. The team made the effort to prepare an agenda before every meeting, however little work was done beyond that.