苏格兰爱丁堡改造低碳商业建筑价值评估报告

征求意见稿

Assessing the Value of Commercial Building Low-carbon Retrofit in Edinburgh City in Scotland
Draft for Comments

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主要发现
Key Messages

- 爱丁堡已有一些正在将现有传统商业建筑进行改造或翻修成零排和低碳理念建筑的具体实例。
- There are concrete examples of retrofitting or refurbishing existing commercial buildings to low-carbon design in Edinburgh
- 初步实物改造方案分析报告显示，保留零排放和低碳设计建筑改造会带来巨大价值。
- A preliminary real option analysis shows a substantial option value in keeping low carbon building (LZB) retrofit option open
- 新建筑应一律强制设计为‘低碳排放建筑改造状态’或‘低碳排放状态’。
- New buildings should be mandated to design in a ‘Low Carbon Building Retrofit Readiness’ status or ‘LCB Readiness’

第一章　引言
Chapter One Introduction

1.1　建筑行业中的能源消耗

1.1 Energy Consumption in the Building Sector

随着全球经济的迅速增长，人类对能源的需求和消耗也日益增大，世界能源危机及其在使用过程中对环境带来的严重负面影响日益突出。截止到 2013 年，在过去的 20 年里，世界总能源消耗在 2013 年增长了 48%，达到 9321 百万吨。同时二氧化碳的排放量增长了 56%，达到 32190 公吨。两者的年平均增长率分别为 2.1% 和 2.4% (图 1)。欧盟多个国家自 1992 年联合国气候变化框架公约（UNFCCC）后，开始致力于处理能源和环境问题。虽然能源消耗问题和二氧化碳排放量在这之后得到了一定程度上的控制，欧盟国家的能源消耗和二氧化碳排放量仍然分别占世界总量的 12% 和 10%（IEA, 2015)。

The rapid growth of the world economy requires substantial demand and consumption for energy, resulting in exhaustion of energy resources and adverse environmental impacts. During the last two decades, the world’s total final energy consumption increased by 48% to 9,321 Mtoe while CO_2 emissions increased by 56%, reaching 32,190 Mt in 2013, with an average annual increase of 2.1% and 2.4% respectively (Fig. 1). The European Union (EU) countries endeavoured to tackle energy and environment issues after the agreement of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992. Although the energy consumption and CO_2 emissions seemed subsequently to be under control (Fig. 2), final energy consumption and CO_2 emissions in the EU contributed 12% and 10% of the world's total numbers respectively (IEA, 2015).

能源末端消耗通常主要以工业部门为主，其他行业包括农业，商业和公共服务业，房地产紧跟其后，其余的部分由交通部门和非能源利用组成。然而，发达国家建筑行业的能耗超过了其他所有的主要行业且占总能耗的20%-40%(Perez-Lombard, et al., 2008)。2004 年欧盟建筑能耗占总能耗的 37%，超过工业部门的 28% 和交通部门的 32%。 到 2010 年，欧盟的建筑能耗占总能耗的比重增加到了 40% (EU Commission, 2010)。以英国为例，建筑的内部温度调节所占能源消耗的比例多达 42%(DECC, 2010) 且该行业占英国二氧化碳排放总量的 43% (DCLG, 2015)。该数据略微高于欧盟的数据，部分原因是由于重工业向服务业转型的结果 (Perez-Lombard, et al., 2008)。

Final energy consumption is usually dominated by the industry sector, followed by others including agriculture, commercial and public services, residential and non-specified, the rest being composed of the transport sector and non-energy use. However, the building sector in developed countries accounts for 20-40% of the total final energy consumption and has exceeded the other major sectors (Perez-Lombard, et al., 2008). In 2004, energy consumption in building sector in the EU was 37% of final energy, bigger than industry (28%) and transport (32%). In 2010, it increased to 40% of total energy consumption in the EU (EU Commission, 2010). In the UK, up to 42% of the energy consumption is spentin heating and cooling the buildings (DECC, 2010) and 43% of all the UK's carbon emissions are caused by the building sector (DCLG, 2015). This is slightly above the European figure and partly due to the shift away from heavy industry towards service sector activities (Perez-Lombard, et al., 2008).

此外，建筑行业仍在扩张。居民建筑和非居民建筑的二氧化碳排放量分别占大约英国二氧化碳总排放量的 25% 和 18% (DECC, 2015)。其中英国的非居民建筑楼层区域预计到 2050 年将增加 35%，同时 60% 的现有建筑仍然处于使用期 (LCICG, 2012)。 苏格兰的公共服务业类建筑在 2013 年排放了 1.2 百万吨二氧化碳当量，占苏格兰温室气体排放量的 2.3%。假如建筑业和其他行业的发展在不善的废物管理制度管理下，或资源利用效率较低的情况下，都将会导致危害环境的严重后果 (DCLG, 2015)。所以，对于建筑业来说，降低能耗，特别是降低碳排放量是应对气候变化问

题的一个重要举措。对建筑业的低碳创新改造将给英国提供一个良好的契机，帮助其提高能源使用效率并降低温室气体排放量。

Furthermore, the building sector is expanding. The energy used by domestic and non-domestic buildings accounts for approximately 25% and 18% of UK carbon emissions (DECC, 2015), and it is expected that non-domestic floor area in the UK will increase by 35% by 2050, while 60% of existing buildings will still be in use (LCICG, 2012). Public sector buildings in Scotland emitted 1.2 $MtCO_2e$, which represented 2.3% of Scottish GHG emissions in 2013. Buildings and other developments can also be environmentally hazardous through poor waste management or inefficient use of resources (DCLG, 2015). Therefore, reducing energy use, and in particular emissions of greenhouse gases (GHGs) in the building sector are essential for tackling climate change issue and retrofitting existing buildings offers a significant opportunity to help improve energy efficiency and reduce greenhouse emissions in the UK.

1.2 苏格兰的建筑业能源政策

1.2 BuildingEnergy Policy in Scotland

苏格兰政府对实现其 2050 年目标（即将苏格兰地区的净温室气体排放量在 1990 的水平上降低 80%）做出了郑重的承诺。其中，中期（2020 年）的目标是将苏格兰地区的净温室气体排放量在 1990 的水平上至少降低 42%。此外，在 2011 年至 2019 期间的每一年的年碳排放量目标须和该期间的排放减少量保持一致，进而使其能够达成中期目标和

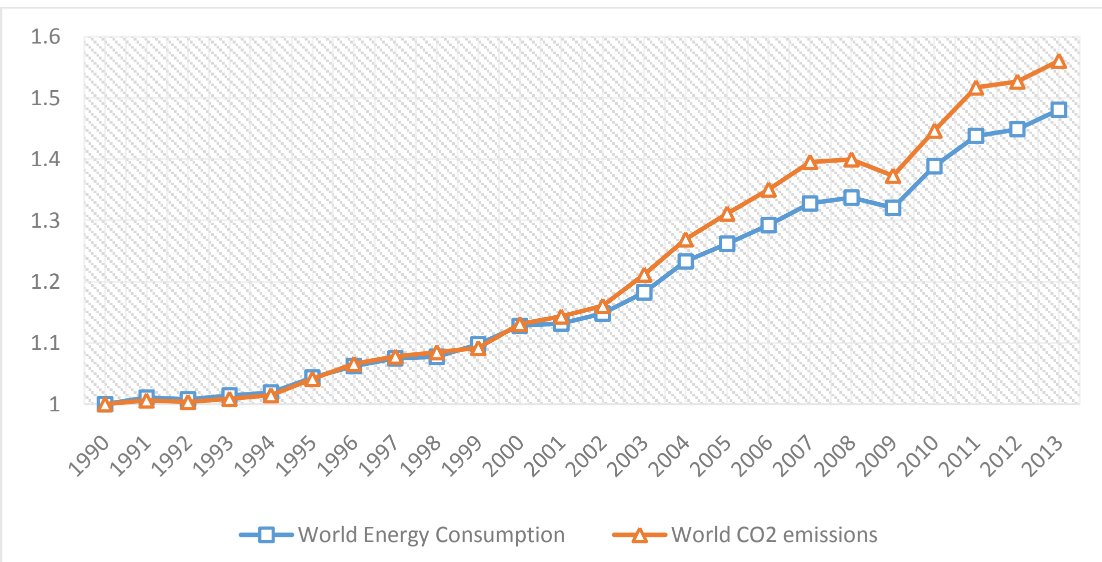

图1–1 自1990年以来世界能源消耗总量和二氧化碳排放量
来源：国际能源署（IEA）

Figure 1. World’s total final energy consumption and CO_2 emissions since 1990. Source: International Energy Agency (IEA).

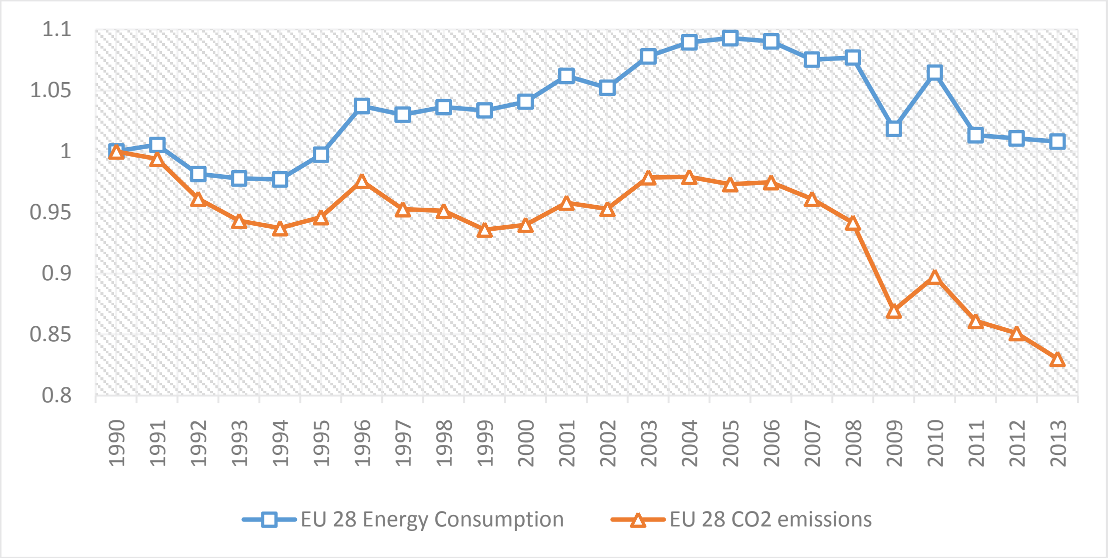

图1-2 自1990年欧盟28个国家总最终能耗和二氧化碳排放量
来源：国际能源署（IEA）

Figure. 2. EU 28 countries’ total final energy consumption and CO_2 emissions since 1990. Source: International Energy Agency (IEA).

2050 目标。另外，2020 年至 2050 年期间的碳排放年度目标必须比前一年度的目标至少减少 3%(气候改变法案 , 2009)。

The Scottish Government have declared a strong commitment to achieve the 2050 target defined as 80% lower net Scottish emissions than the 1990 baseline. The interim target, which is set for year 2020, is at least 42% lower net Scottish emissions than the baseline. Moreover, for each year in the period 2011-2019, the annual carbon emission target must be set at an amount that is consistent with a reduction over that period of net Scottish emissions amounts which would allow the interim and the 2050 target to be met. For each year in the period 2020-2050, the target must be set at an amount that is at least 3% less than the target for the preceding year (Climate Change Bill, 2009).

苏格兰建筑行动法案是由议会于 2003 年 2 月 20 日通过的，该法案对建筑、建筑标准、核查和认证、建筑物权证等方面制订了相关规定。之后，2007 年沙利文报告提出了关于建设低碳建筑的路线图、降低碳排放量的期望和建筑标准中涉及能源利用效率等问题。该报告同时还建议所有非居民建筑物的所有者应执行对二氧化碳排放量和能源利用的评估并同时开展建筑升级改造工程。

The bill for the Building (Scotland) Act was passed by the parliament on 20th February 2003, including provisions with respect to buildings, building standards, verification and certification, building warrants etc. In 2007, the Sullivan Report proposed a route map for delivery of very low carbon buildings, setting aspirations for carbon abatement and energy efficiency within building standards. The report also suggestedthat all owners of non-domestic buildings should conduct a carbon and energy assessment and produce a programme for upgrading.

2007 年沙利文报告同时提出关于如何提升现有建筑物碳的能源利用率的方法的若干设想。该报告建议引入一项法律条例，条例要求所有非居民建筑的所有者实施对二氧化碳排放量和能源利用的评估，并同时开展建筑升级改造工程，该条例已被纳入苏格兰气候变化法案第 50 条。

The Sullivan Report (2007) also considered ways in which carbon and energy performance of existing buildings can be improved. Introduction of legislation to require all owners of non-domestic buildings to conduct assessments of carbon and energy and produce a programme for upgrading were recommended, and led to the inclusion of Section 50 in the Climate Change (Scotland) Bill.

2009 苏格兰气候变化行动法案重点强调了非居民建筑的能源利用情况、提升能源利用率和再生热能等问题。同年，苏格兰政府发布了可再生能源框架以支持欧盟可再生能源的需求将在 2020 年达到 20% 的目标。

Therefore, energy performance of non-domestic buildings, and promotion of energy efficiency and renewable heat were emphasized in the 2009 Climate Change (Scotland) Act. In the same year, the Scottish Government issued the Renewable Energy Framework to advocate the EU target of 20% renewable energy by 2020, and play its role in meeting the contribution proposed for the UK for 15% renewable energy and aim to go further than that (to 20%).

2007 年沙利文报告中有关的建议基本全已实施运行。在最近发表的 2013 年《沙利文报告 - 苏格兰低碳建筑标准策略》中，为了能让低碳建筑标准更好的实施，该报告承继了以往报告中的建议，并回顾了为应对欧盟自 2019 年要求建立‘近零排放’新建筑的要求的相关能源标准。

Almost all of the recommendations from the original Sullivan Report in 2007 have now been taken forward. In the most recently Sullivan Report in 2013: A Low Carbon Building Standards Strategy for Scotland: to support a more successful implementation of low carbon building standards, and subject to the previous recommendation, subsequent review of energy standards were suggested to be programmed to align with the EU Directive requirement for ‘nearly zero energy’ new buildings from 2019.

苏格兰政府同时利用该建筑标准和规划系统帮助建设低碳建筑。苏格兰政府的建筑标准部门在 2015 年 10 月 1 日发布了关于建筑标准规则的新指导信息。其中包括主要针对第六部分（能源）居民建筑和非居民建筑的新技术手册。该标准现在同时适用于非居民建筑的扩张，且该建筑的总占地面积范围将扩大至少 100 平方米或者 25%。图 1-3 总结了苏格兰建筑能源政策在过去 12 年的发展。

low carbon buildings. The Scottish Government, Building Standards Division (BSD) has published

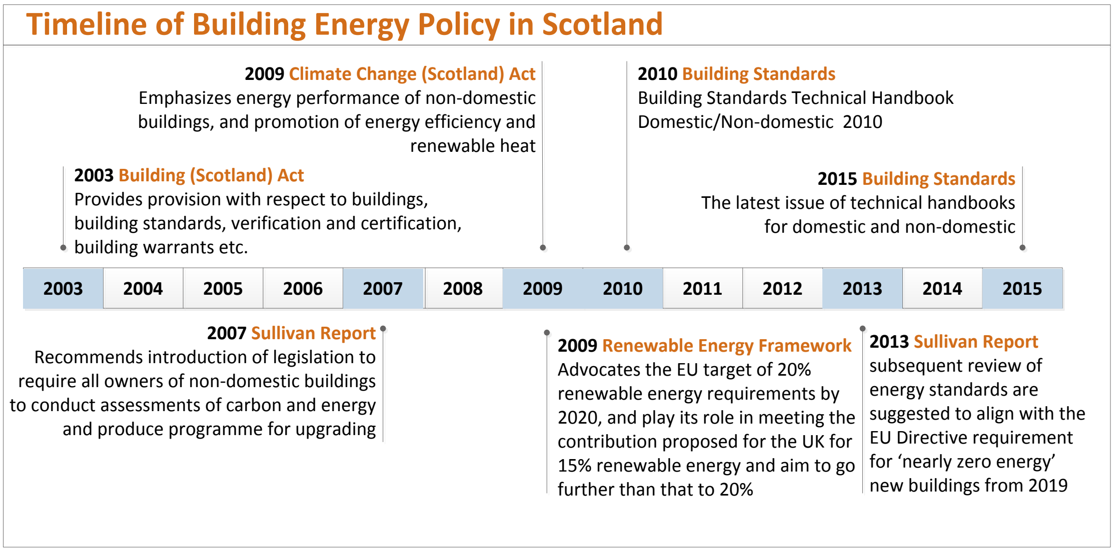

图1-3　关于苏格兰建筑能源政策发展的时间轴
Figure. 3. Timeline of Building Energy Policy in Scotland

new guidance regarding Building Standards compliance from 1 October 2015, including new Technical Handbooks with major revisions to Section 6 (Energy) Domestic & Non-domestic. The standard now applies to extensions to non-domestic buildings that increase the total area by more than 100 m^2 or 25%. Figure 3 shows the timeline of policy regarding building energy in Scotland over 12 years.

1.3　关于改造非居民建筑的文献

1.3 Literature on Retrofitting of Non-domestic Buildings

建筑改造的主要目的是通过利用一种成本效益好的方案重建已有的建筑从而将其益处最大化 (Markus, 1979)。建筑改造在建筑遭到严重破坏、折旧和房地产的投资价值有所损失的情况下可立即进行。然而，由于如今的传统经济效益分析理论中融入了更多关于社会和环境因素对商业的影响作用，曼斯菲尔德（2009）建议涉及到企业社会责任（CSR）和社会责任性投资（SRI）的可持续性政策将可能对建筑改造的行动起到推动作用，从而致力于解决能源效率的提升、降低碳排放量和其他可持续性发展问题。

The main proposal for retrofitting is to extend the beneficial use of an existing building by taking a cost-effective alternative to redevelopment (Markus, 1979). Retrofitting may be initiated suddenly due to profound damage, or driven by depreciation and the loss of a property's investment value (Aikivouri, 1996). However, since the conventional economic performance analysis has been extended with more consideration of the social and environmental impacts of a business, Mansfield (2009) suggested that sustainability policies with respect to the corporate social responsibility (CSR) and socially responsible investment (SRI) may bring forward the timing of retrofitting, thus making an effort to address energy efficiency, CO_2 emissions and other sustainability issues.

马等（2012）认为建筑改造的过程分为五个步骤，第一步是工程的开展和改造前的调查；第二步是能源审查和效益评估；第三步是改造方案的确认；第四步是执行和投产；第五步是确认和核实节能减排的效果。成功的建筑改造取决于多个因素包括政策和法规、改造技术，建筑的具体信息和其他不确定因素。由于现有可利用的改造技术手段较多，所以准确可靠的预测和确认成本效益最高的改造手段对于建筑改造是至关重要的。不同技术手段的效益评估通常是通过能耗模拟和能耗模型进行的。

Ma et al. (2012) identified five steps in the process of a building retrofit: project set up and pre-retrofit survey, energy audit and performance assessment, identification of retrofit options, implementation and commissioning and the last one validation and verification of energy saving. A successful retrofit programme depends on many factors including policy and regulation, retrofit technologies, building specific information and other uncertainties. Since there are a wide range of retrofit technologies readily available, hence reliable estimation and the most cost-effective retrofit options identification for particular projects on existing buildings is essential for sustainable building retrofit. Performance of different options is commonly evaluated using energy simulation and modelling.

此外，经济可行性分析可以用来比较改造技术并得出最有经济效益的改造方法，同时还可以衡量该方法的投资及收益 (Ma et al., 2012)。 为了降低建筑业的温室气体排放量，克赫斯特等（2011）通过对宾夕法尼亚匹兹堡和德克萨斯州奥斯汀两个案例研究了现有的居民建筑和非居民建筑改造的成本和收益。他们分析了改造所花费的资本、人工费、改造后的消费者净收益，并对资金约束的权衡、社会储蓄、和减少温室气体的排放进行了评估。其中，净现值（NPV）是用于衡量净储蓄的指标。他们的研究结果表明，国家的股票市场、需求和效率的不确定性在很大程度上影响预期结果。

Ma et al. (2012) identified five steps in the process of a building retrofit: project set up and pre-retrofit survey, energy audit and performance assessment, identification of retrofit options, implementation and commissioning and the last one validation and verification of energy saving. A successful retrofit programme depends on many factors including policy and regulation, retrofit technologies, building specific information and other uncertainties. Since there are a wide range of retrofit technologies readily available, hence reliable estimation and the most cost-effective retrofit options identification for particular projects on existing buildings is essential for sustainable building retrofit. Performance of different options is commonly evaluated using energy simulation and modelling.

瑞萨那和乔德瑞（2013）通过运用建筑能源系统的综合工程经济评价模型研究完善了上述报告。为了提高对改造技术进行精确性能估算的速度，他们修改了标准方法并用 TRNSYS 建立能源模型。同时，布尔等通过运用动态能耗模拟 EnergyPlus7.2 版本和 jEPlus1.4 版本模型对英国学校的改造方法的能源效率进行评估。由于这些建筑改造将持续很多年，他们引入了成本和碳排放量的周期影响概念。他们研究发现获得碳回报的时间比财务回报和其他所有需要后续重新改造所投入的方法所需要的回报的都要短。

Rysanek and Choudhary (2013) augmented the above study by employing a combined engineering-economic assessment model of a building energy system. They modified the standard approach to building energy modelling by using TRNSYS in order to improve the speed at which accurate performance estimations of numerous retrofit options are made. Meanwhile, Bull et al. assessed energy efficient retrofit options for schools in the UK by conducting dynamic energy simulations of a range of energy retrofit measures using EnergyPlus v.7.2 and jEPlus v. 1.4. They introduced life cycle effects on costs and carbon emissions since these retrofits will last for many years. They found that carbon payback is shorter than financial payback and all options and combination of options repaid the carbon invested in them.

在麦克阿瑟和乔夫在 2015 年报告中，其中的一个案例研究，包含了一大批全球租户和他们的英国投资组合中的 40 处房产。他们的改造目标是在 2007 年至 2017 年期间让投资组合的碳排放量降低 50%。 麦克阿瑟和乔夫认为让该组合达到其目标的最佳机会是运用历史能源使用数据对该组合进行评估和分类。阿斯特等 2016 年提出了关于改造现有建筑的能源效率规划的经济学分析，并以此倡导全新低碳排放建筑的发展。

One of the case studies in McArthur and Jofeh’s research (2015) involved a large global tenant with 40 properties in their UK portfolio and their retrofitting goal is to reduce portfolio carbon emissions by 50% between 2007 and 2017. McArthur and Jofeh identified the best opportunities in the portfolio to achieve the goal by assessing and sorting portfolios using historic energy use data. Aste et al. (2016) also presented economic analysis referring to local energy efficiency programs for retrofitting existing building and for promoting new low emissions buildings.

1.4 报告结构

1.4 Report Structure

瑞萨那和乔德瑞 2013 年提出，当节约能源和降低排放成为过去十年里首要目标的同时，全球经济衰退和之后的公共债务危机也使‘节省能源效率的成本‘成为一个流行改造现有建筑的基本原理。不同的建筑有其各自独特的建筑学、地理学和使用特点，因此改造方法必须在建筑群内进行合理的分析。同时通过运用计算建筑能源模型来调查每个改造方法的

成本和收益。

Whilst energy saving and emission reduction might have been the ‘top priority’ in the previous decade, the global economy recession and the following public debt crisis made ‘energy efficiency cost saving’ as the popular rationale for retrofitting existing buildings (Rysanek and Choudhary, 2013). Different types of building exhibit unique architectural, geographical and operational characteristics, therefore retrofit options must be rationally analysed for every individual building in a building stock, and computational building energy models must be employed to investigate the cost and benefit of these options.

同时，英国商业建筑的改造进度仍然缓慢和分散。英国和美国的新研究提出需要重大的改革来推动大规模的建筑改造。同时全新的创新型融资模型可以创造新的机遇(迪克森，2014)。此外，尽管已有许多关于居民建筑减排和新建筑的研究，但现有非居民建筑的不同种类的高效低碳设计改造现有研究是很有限的。此外，大部分的研究都主要针对现有商业办公建筑能源和环境绩效的数值模拟，因此十分需要增加针对非居民建筑改造的实例研究。

Meanwhile, progress in retrofitting the UK’s commercial properties continues to be slow and fragmented. New research from the UK and USA suggests that radical changes are needed to drive large-scale retrofitting, and that new and innovative models of financing can create new opportunities (Dixon, 2014). Moreover, despite a number of studies on carbon reduction in residential buildings and new buildings, there is limited research into the disaggregated potential for energy and carbon by retrofitting the existing non-domestic buildings with more efficient and low-carbon designs. Also, most studies on energy and environmental performance of the retrofit of existing commercial office buildings were carried out based on numerical simulations, more studies with practical case studies on non-domestic building retrofits are essentially needed.

因此，此报告通过对改造方案的价值研究来评估改造爱丁堡现有商业建筑的潜在收益。此报告的目的是对英国的非居民建筑改造的经济效益进行评估并通过提供政策机制来缩小差距。模型的一般假设是基于对爱丁堡六个商业建筑改造的技术性和财务表现的分析。此报告同时提出新建筑应被设计为‘低碳排放建筑改造状态’或‘低碳排放状态’。

Therefore, this report evaluates the potential benefits from retrofitting existing commercial buildings in Edinburgh City through assessing the option value of retrofitting. The purpose of this paper is to assess the economics in the retrofit in non-domestic buildings in UK, and provide policy mechanisms to bridge the gap. The generic assumption of the model is based on analysing the technical and financial performance of six commercial building retrofit cases in Edinburgh City. The report also proposes that new buildings should be designed in a ‘Low Carbon Building Retrofit Readiness’ status or ‘LCB Readiness’.

报告的结构如下：第二章概述评估方法。评估方法包括技术评估机制、财务现金流估值法和评估将新建筑设计成低碳排放建筑价值的新兴实物期权。第三章呈现技术实例研究。第四章展现模型结果概述及其潜在的结果影响。

The report is structured as follows: Chapter Two gives an overview of evaluation methodologies, incl. the technology assessment mechanism, financial cash flow valuation method, and the novel real option approach for assessing the value of making new buildings designed in a low carbon retrofit readiness status. The Chapter Three presents the technical case studies. Chapter Four presents the model results and outlines the potential implications.

第二章　方法论
Chapter Two Methodology

传统的金融期权定价方法采用的是实物期权分析（ROA）。该方法自二十世纪七十年代开始便用于不确定性或灵活性较大的实物资产估值 (梅尔斯 ,1977)。这是因为另一种确定性现值法无法获得每个决策点 [1] 的连续期权价值。此报告使用 ROA 模型，调查研究将建筑改造为低碳排放建筑的经济效益。

The traditional financial option pricing methodology, the Real Option Approach (ROA), has been applied to valuing real assets which are either uncertain or flexible since the 1970s (Myers, 1977). This is because an alternative, deterministic net present value method fails to capture the option value involved in the sequential decision-making at each decision node . This study applies ROA to investigate the economics of retrofitting a building to low carbon building status.

现有关于 ROA 在能源部门的研究可以分为三组 : (1) 在市场不确定的情况下对个人投资决策的分析，例如：电力、化石燃料、和 / 或碳市场 (罗斯维尔 , 2006; 福汀等 , 2008; 斯哥约瓦等 , 2008; 杨等 , 2008); (2)R&D 的最优化和公司的商业化及能源技术的普及 (库巴罗路等 , 2005; 谭等 , 2007; 史迪奇等 , 2007); (3) 在不确定或较为灵活的能源系统下的公共能源政策决策的调查研究 (李和新恩 , 2005; 马雷克和卡皮奥 , 2006; 林等 , 2007; 福兹和斯哥约瓦 , 2010; 朱和范 , 2011)。

The existing ROA studies in the energy sector could be classified into three clusters: (1) analysis of the private investment decisions under market uncertainty, e.g. electricity, fossil fuel, and/or carbon markets (Rothwell, 2006; Fortin et al, 2008; Szolgayova et al, 2008; Yang et al, 2008); (2) optimisation of R&D , commercialisation and diffusion of energy technologies of a firm (Kumbaroglu et al, 2005; Tan et al, 2007; Siddiqui et al, 2007); (3) investigation of public energy policy decision-making in an uncertain or flexible energy system (Lee and Shih, 2005; Marreco and Carpio, 2006; Lin et al, 2007; Fuss and Szolgayova, 2010; Zhu and Fan, 2011).

此报告的研究方法论是建立于上述 ROA 研究成果上的。我们采用项目投资人（例如商业建筑的投资人）的角度来调查分析商业建筑改造后的期权价值。不确定性是推动期权价值的一个因素。若干不确定因素可能潜在地影

1 作为实物期权模型的一部分，投资决策是在每一个决策点做出的。
1 As a part of a real option model, the investment decision is made at each decision node.

响投资决策，其中包含技术贡献率（或自适应率），全球低碳碳建筑的内部容量，天然气、电力的价格和碳价格。

The methodology of this study builds on the knowledge and understanding gained from the existing ROA studies described above. We take the perspective of a project investor (e.g. commercial building investor) investigating the value of exercising a retrofit option in a commercial building. Uncertainty is the driver of the option value. A number of uncertainties may potentially affect this investment decision, including the technology progress ratio (or learning rate), global installed capacity of low carbon building, gas and electricity prices and carbon price. High learning rate would drive down the economic of scales, which helps to increase attraction of retrofitting option. The capacity should be examined to provide constraint of low carbon building worldwide. The price of gas and electricity price and carbon price are both positively correlated to building retrofitting.

由于在模化碳价格的过程中存在显著的政策不确定因素，因此在现实中政策变化的影响比碳市场更有可能性成为低碳碳建筑改造的推动因素。在此报告中，我们简化了假设，并假定投资决策仅由市场因素所决定。为了确定改造低碳建筑的可能性，随机自由现金流模型被同于为了预估低碳碳建筑每一年产生的未来现金流的现值，建立了随机自由现金流模型。第T年未来现金流的现值计算方法为：

Because there are significant policy uncertainties in modelling the carbon price and the regulatory motive other than existing carbon markets are, in reality, likely a possible driver for low carbon building retrofit. In this study, we simplify the assumption and assume the investment is driven solely by market factors. To identify the probability of retrofitting a low-carbon building, a stochastic free cash flow model has been built to estimate each year’s net present value of future cash flows generated by low carbon retrofit. The net present value of the future cash flow at year T is given by:

$$PV_T(S_t, I_t, O_t, F_t) = \sum_{n=T}^{L} \frac{(S_t - I_t - O_t - F_t)}{(1+q)^t} \quad (2\text{-}1)$$

t 年 商业建筑在决策点时的使用寿命

t year Present life of the commercial building at a decision node

L 年 建筑的使用年限

L year Lifetime of building

PV_T \$ 第T年的未来现金流的现值

PV_T \$ Present value of the future cash flow at year T

S_t \$ 第T年的租金收入

S_t \$ Revenue from rental at year t

I_t \$ 第T年的投资现金流

I_t \$ Investing cash flow at year t

O_t \$ 第T年的非燃料和非碳运营现金流量

O_t \$ Non-fuel and non-carbon operating cash flow at year t

F_t \$ 第T年电力、天谈起和碳的费用

Ft \$ Payment for electricity, gas and carbon at year t

q % 私人票据贴现率 (所需的内部收益率)

q % Private Discount Rate (required internal rate of return)

将建筑改造成低碳建筑的主要驱动因素是假设建筑物所带来的收入会随着租金的提升、二氧化碳排放量和能源花费的降低而有所提升。由于改造后未来价值的不确定性，此报告采用强有力的概率分析方法蒙特卡洛来分析此种情况。

The main driver for retrofitting a building to low carbon building is assumed to be an increase in revenue driven by increasing rent and a reduction of carbon and energy bill. The value of a future retrofit is inherently uncertain and a robust exploration with probabilistic Monte-Carlo analysis has been conducted to take this into consideration.

理论上，增加时间序列的个数会导致高期货价值，但是实际的投资决策更可能是每一年做出的，因为评估一个高等投资决策会产生成魔沉没成本（例如详细的施工设计和经济评估，特别的电路板组件）。因此，此报告运用近似等同于真实的决策过程的离散时间间隔的方法进行分析 (普兰缇哥 , 1998).。 此处假设决策仅仅在每一年的年末被提出。换句话说，如果一个改造项目在第 t 年开始实施，进一步的设施升级可以在 t+N 年进行。对于一个拥有 50 年经济寿命的建筑来说，改造过程有 24 个时间序列，或决策点。

In theory, increasing the number of time-steps would result in higher option values, but actual investment decisions are more likely to be made on an annual basis, because the process to evaluate an upgrade investment decision would incur sunk costs (e.g. detailed engineering and economic assessment, special board assemblies). Therefore, the study is conducted with discrete time intervals to approximate the real decision-making process (Plantinga, 1998). It has been assumed that the decision is only made at the end of each year. In other words, if one retrofit takes place in year t, a further upgrade could also be made at year t + N. For a 50 year economic lifetime there are therefore 24 time-steps, or decision nodes.

在每个决策点，改造一座商业建筑的决策取决于一次改造资本投资的成本和未来节省的成本之总和的平衡及收益增长。

At each decision node, the decision to retrofit a commercial building depends upon the balance between the cost of a one-off capital investment to retrofit and the sum of future cost savings and revenue increase.

技术自适应学习率在此报告中被假设转化为低碳技术打进市场将降低改造成本的概念，因此这些因素对于决定改造后期权的价

值是至关重要的。这些自适应学习率主要针对于建筑改造的总资本成本。其中改造成本（RCOST）是由单因素学习曲线模型（阿尔卑斯 ,2008; 乔津歌 , 2010）给出的：

Technology learning rates, assumed in this study to be translated into a reduction of the retrofit cost with new low carbon technologies entering the market, are therefore critical to determine the value of the option considered for retrofitting. These learning rates focus on the total capital cost of retrofitting the building. The RCOST is here modelled by a one-factor learning curve model (Alberth, 2008; Junginger et al, 2010), given by:

$$RCOST_n = RCOST_0 \left(\frac{Cap_n}{Cap_0}\right)^{\log(1-m)} \qquad (2\text{-}2)$$

$RCOST_n$ 英镑 第n年的改造成本

$RCOST_n$ GBP Retrofit cost at year n

Cap_n 平方米 第n年的低碳商业建筑的全球容量

Cap_n m^2 Global capacity of low carbon commercial building at year n

m 自适应学习率

m Learning rate

为了简便起见，假设技术学习率和全球部署能力率将不会受到其他假设或其他模型的影响，因此它们是外部的、相互独立的价值。有关低碳改造学习率的估测研究是很稀少的。此报告假设学习率为 5%。

For simplicity, it is assumed that the technology learning rate and the global deployment capacity rate are not affected by other assumptions or the model specification, so that they are exogenous, independent values. There is a lack of study estimating the learning rate for low carbon retrofit. The study assumes a learning rate of 5%.

另外，技术学习率 m 和全球低碳改造的发电机容量被假设符合随机性（此假设符合麦当劳和 施屯侯塞 (2001) 的研究关于历史能源技术学习率不是常量而是随机变化的研究）。然而有关证明低碳建筑的学习率和部署率符合随机过程的文献十分缺乏。 基于我们对以往学习和部署的过程的最佳理解，假设的学习率是假设符合均值回归模型且有在其长期均值假设中的假设回复率的 0.5 的趋势中上下徘徊。同样地，假设的安装容量的部署率遵从随机变化且在其假设均值回复率 0.25 中的上下徘徊。

In addition, it is assumed that a stochastic process applies to the technology learning rate, m, and the rate of global installed generation capacity with low carbon retrofit (this follows findings from McDonald and Schrattenholzer (2001) who showed that the historical energy technology learning rates is not constant and varies stochastically). However, there is a lack of literatures to justify the stochastic process of learning rates and deployment rates for low carbon building. Based on our best knowledge with a reference of past learning and deployment process, the hypothetical learning rate is assumed to follow a mean reverting process and tends to drift towards its long term mean assumption at a hypothetical reversion rate of 0.5; similarly, the hypothetical deployment rate of installed capacity varies stochastically and drifts towards its mean value with a mean hypothetical reversion rate of 0.25.

低碳建筑的技术学习率和部署率的过程可以写成以下形式：

The process of technology learning rate and deployment rate of low carbon building capacity can be written as:

$$Q_t = Q_{t-1} + \omega_m(Q_L - Q_{t-1}) + Z_m \qquad (2\text{-}3)$$

ω_m		均值回转率
ω_m		Mean reverting rate
Q_t	$	第t年率
Q_t	$	Rate at year t
Q_L	$	长期均衡点
Q_L	$	Long run equilibrium Rate
Z		标准韦纳过程的随机变量
Z		Random variable following a standard Wiener process

因此改造的主要障碍是建造低碳建筑所必要的预付资本投资。电力价格、天然气价格和碳价格不确定性的随机过程由均值回复过程模型来实现，如等式 2-4。

The main barrier to the retrofit is thus the cost of the upfront capital investment necessary to make a building in low carbon status. To represent the uncertainty for electricity price, gas price and carbon price a stochastic process is modelled by a mean reverting process, as in Equation 2-4.

$$P_t = P_{t-1}(1+\alpha) + \omega_g(P_L - P_{t-1}) + Z_g \qquad (2\text{-}4)$$

α	-	漂移系数
α	-	Drift factor (growth)
ω_g	-	均值回复率
ω_g	-	Mean reverting rate
P_t	$	第t年的价格
P_t	$	Price at year t
P_L	$	长期均衡价格
P_L	$	Long run equilibrium price
Z_g	-	标准韦纳过程下的随机变量
Z_g	-	Random variable following a standard Wiener process

为了补充此报告中模型假设中的不确定因素，采用敏感性分析被采用调查分析改造期权在不同电力、天然气、学习率、改造所需的资本和碳价格增长的情况下的价值。 行使期权改造建筑的界限的设立目的是估计每个决策点形式齐全的可能性，。因此 ROA 决策框架在具备以下几种特点时是一个较复杂的模型：

To complement with uncertainties in the model assumptions for this study, a sensitivity analysis is conducted to investigate the value of retrofit options for different electricity, gas and carbon price growth scenarios as well as different learning rates and required capital for upgrade. The boundary for exercising the option to retrofit the building aims to estimate the probability of exercising the option at each decision node. Thus the ROA decision-making framework is a complex model with the following characteristics:

- 这是一个美式的期权，即期权可以在从现在到任何一个到期日内行使。
- It is an American style claim option, i.e. options could be exercised anytime from

now to any expiry date;

- 由于行使期权时产生了沉没成本，每一年只考虑一个决策点。
- Because of the sunk cost in exercising the option, only one decision node per year is considered;
- 在基础情景中电力和天然气的价格均假设为不会增长，所以在该情况下，电力和煤炭价格的漂移（即增长）为零。
- In the baseline scenario, it is assumed that both the electricity price and the gas price are not growing, thus in that case, the drift (i.e. growth) of electricity and coal price is low; and
- 后项算法被用于估计最佳行使界限。
- A backward looking algorithm is used to estimate the optimal exercise boundary.

在评估一个改造期权时（即改造的净收益），采用四步启发式方法被采用于评估升级一个建筑的期权价值：

In evaluating a retrofit option (i.e. the net benefit of retrofit), a heuristic approach in four steps is applied to evaluate options to upgrade a building:

（a）确定每一个处于随机过程变量的样本轨迹

(a) Identify the sample paths for each variable undergoing a stochastic process;

（b）基于现今的改造成本和随机变量（即改造成本，燃料价格，电力价格，碳价格，部署率和学习率）的信息，使用最小二乘回归方法和蒙特卡罗方法来估计每个决策点升级的可能性和改造期权的价值。

(b) Use a least square regression method with Monte-Carlo simulation to estimate the probability of upgrade and the value of the retrofit option at each option decision node, based on the current retrofit cost and the current information of stochastic variables (i.e. retrofit cost, fuel price, electricity price, carbon, deployment rate, and learning rate);

（c）对经后项演绎方法行使改造期权的最初价值进行估算。

(c) Estimate the initial value of the retrofit option exercised through a backward deduction approach;

（d）计算第 0 年的改造期权平均值

(c) Estimate the initial value of the retrofit option exercised through a backward deduction approach;

预估的建筑租金在初始时期 t 的价格为x_t。很明显x_t取决于上一时期所实现的房租水平，即$x_t \in \{x_0, \ldots, x_{t-1}\}$。假设当下低碳建筑在市场 I 的租金水平记为$e_t$。如果做出了一个改造决策，则租金水平 (x_t) 将成为当下低碳建筑的市场租金水平e_t和下一时期低碳建筑的初始市场租金水平e_t，即$x_{t+1} = e_t$。若未做出改造决策，则市场租金水平将会维持在x_t且$x_{t+1} = x_t$。改造期权的价值可以用以下的贝尔曼方程（2-5）来估计。

The estimated building rental level at the beginning of period t isx_t . It is clear that x_t depends on the realizations of the rental level in the previous periods, i.e.,$x_t \in \{x_0, \ldots, x_{t-1}\}$. Suppose that the current rental level for low-carbon building at the market I denoteds e_t If an retrofit decision is made, then the rental level (x_t) becomes the current low carbon building market rental levele_t and the beginning low carbon building market rental level of next period is e_t , i.e., $x_{t+1} = e_t$. If no retrofit decision is made, then the market rental level remains at x_t and $x_{t+1} = x_t$. The value of retrofit options can be evaluated by the following Bellman equation (2-5).

$$V_t(x_t, e_t, Q_t, P_t) = max \begin{Bmatrix} \frac{1}{1+r} b_{t+1}(e_t, Q_t, P_t) - k_t + \frac{1}{1+r} E[V_{t+1}(e_t, e_{t+1} Q_t, P_t)], \\ \frac{1}{1+r} E[V_{t+1}(x_t, e_{t+1}, Q_{t+1}, P_{t+1})] \end{Bmatrix} \tag{2-5}$$

这里的期望的取值是根据下一时期的市场改造成本水平和终值$V_T(x_T\ ,e_T)$=0。

where the expectation is taken with respect to the market retrofit cost level of next period and the terminal value V_T (x_T ,e_T)=0.

t 年 在决策点是建筑的现有的经济寿命

t year Present economic life of the building at a decision node

T 年 建筑的寿命

T years Lifetime of the building

V_t \$ 第t年改造方案的随机价值

Vt \$ Stochastic value of the retrofit option(s) at year t

$E[V_{t+1}]$ \$ 第t+1年预估的改造方案价值

$E[V_{t+1}]$ \$ Estimated value of the retrofit option at year t+1

b_{t+1} \$ 第t+1年改造方案的运营现金流现值的预估边际效益

在第 t 年行使

b_{t+1} \$ Estimated marginal benefit in the present value of operating cashflow at year t+1 with a retrofit option exercised at year t

x_t $ 第t年的建筑租金水平

x_t $ Building rental level at year t

e_t $ 第t年的预估低碳建筑的市场租金水平（估计值）

e_t $ Estimated market rental level for low carbon building at year t (estimated)

r % 零风险折现率

r % Risk-free real discount rate

k_t $ 第t年的一次建筑改造的资本投资成本

k_t $ One-off capital cost investment to retrofit the building at year t

决定是否在第 0 年对未来的低碳技术做出额外投资的决定取决于所需的额外投资的现值 S0 和可以用于改造建筑方法的均值。换言之，对低碳建筑的额外投资会被证明合理当投资的现值（I0）低于方案的预期价值（2-6）。

The decision to make an additional investment at year 0 to future-proof low carbon readiness depends on the present value of the additional investment required, S0, and the mean value of the option to be able to retrofit the building. In other words, an additional investment to future-proof a building with low carbon readiness statuswould be justified if the present value of the investment (I0) is lower than the anticipated value of the option (2-6).

投 资， 当 $V_0 \geq S_0$ 不 投 资，当 $V_0 < S_0$ (2-6)

"Invest,if" $V_0 \geq S_0$不 Do Not "Invest,if " $V_0 < S_0$ (2-6)

S_0 $ 第0年对于未来商业建筑的额外投资

S_0 $ Additional investment at year 0 to future-proof the commercial building

V_0 $ 能将建筑改造成低碳建筑的方案价值

V_0 $ Value of the option to be able to retrofit the building to a low carbo status

值得注意的是，在现实中，对建筑的额外投资在现实中需根据地点本身的特点进行详细的设计研究。此报告虽没有介绍一个运用于典型案例的方法论，但在实际工程中仍然可作为决策参考。同时，初始投资 I0 并没有直接添加入现金流模型。模型的价值 V0 以美元计价，并采用能在不同假设下的天然气价格，电力的卖出价，碳价格，技术学习率和部署率能将建筑改造成低碳建筑的成熟方案。是否投资商业建筑的决策不在此报告的研究范围。

It should be noted that the investment required to future-proof the building, I0, is site specific, and would, in practice, require a detailed design study. The scope of this analysis is limited to introducing a methodology applied to an illustrative case study, which could also be used to assist decision-making in real projects. Also, the initial investment I0 is not added directly to the cash flow model. The outcome of the model is the value V0, in $, of the option of being able to retrofit the building under the different assumptions for gas price, electricity selling price, carbon price technology learning rate and deployment rate. The decision to invest or not in a commercial building is out of the scope of this study.

第三章　案例研究
Chapter Three Case Studies

此报告对苏格兰爱丁堡六座商业建筑案例进行了相关评论，其中包括：

The study reviews six commercial building case studies at Edinburgh City, Scotland, including:

- 爱丁堡诺顿公园大厦
- Norton Park Building, Edinburgh
- 电话房
- Telephone House
- 阿福科特小路周边
- Advocate’s Close
- 斯科顿楼
- Scotstoun House
- 克雷米勒中心
- Space Craigmillar
- 低碳创新爱丁堡中心
- Edinburgh Centre for Carbon Innovation

爱丁堡诺顿公园大厦
Norton Park Building, Edinburgh

背景
Background

诺顿公园大厦的前身是一所二等景点学校。该大厦的办公室主要用于爱丁堡的自愿者组织。在二十世纪 90 年代早期，由于该学校属于一所多余的学校，洛锡安区地区委员会将诺顿大厦改作为一个适合做慈善事业的办事处。该大厦的所有者，阿尔比恩信托希望这个在 1998 年竣工的建筑能进行一次环境再开发。该大厦的很多方面经评测需要翻新，其中包括能源使用、建筑材料、照明、室内用水、通风系统和制冷。

Norton Park Building is a former school listed as Grade II. Its offices are mainly used for voluntary organizations in Edinburgh. In the early years of 1990s, the Lothian Regional Council selected Norton Park Building, as a suitable office for charities. The owner of the building, The Albion Trust wanted an environmental redevelopment of the building which was completed in 1998. Many aspects of the building were assessed and renovated, including energy use, construction materials, lighting, water consumption, ventilation and cooling.

大厦的描述、设计和建设
Building Description, Design & Construction

形态结构
Form and Fabric

诺顿公园是一个属于二等景点的，拥有黑

色板岩屋顶的红砂岩的建筑。当其内部结构进行节能翻新时，其外观将受到很少影响。

Norton Park is a red sandstone Grade II listed building with a black slate roof. There was little change made to the external appearance while energy efficient refurbishment was made to its fabric.

墙壁和屋顶将大量使用矿物棉材料装修。墙壁现具备 0.2 W/m^2K 的 U 值同时屋顶具有 0.1 W/m^2K 的 U 值。原来的框格窗新装修了木制结构的充氩双层玻璃。窗户现在拥有 0.85 W/m^2K 的 U 值。

The walls and roof were highly insulated with mineral wool. Walls now have a U-value of 0.2 W/m^2K and the roof has a U-value of 0.1 W/m^2K. Wooden-framed, argon-filled double glazing was installed in addition to the original sash windows. The windows now have a U-value of 0.85 W/m^2K.

通风系统

Ventilation

大厦的通风系统现被安装在建筑的中央核心位置，该系统通宵运行。在夏季可以保持凉爽适宜的温度，在寒冷的冬季将从室外进入室内的空气进行加热并维持在 20.5 摄氏度。太阳能供暖系统通过已被加热的屋顶石板给大厦顶层的空气进行预热。

A ventilation system has been installed in the central core of the building. The system run overnight in the summer to keep comfort temperature and in the winter it heats the incoming air to a constant 20.5 degree Celsius. A solar heating system makes use of air that is warmed by being drawn under the roof slates to preheat the air supply to the top floor of the building.

采暖

Heating

暖气管和空气处理机组的供暖由两个燃气冷凝锅炉代替 1910 年的锅炉。该大厦被划分了 15 个供暖区，每个区的恒温器均被设置为与机械通风设备提供的新鲜空气相同的 20.5 摄氏度。该大厦供暖系统的运营时间为周一至周四上午 7：30 到下午 3:00，周五的上午 7：30 到下午的 2：00。

The existing boiler from 1910 has been replaced by two gas-fired condensing boilers to supply heat to radiators and to air-handling units. The building is divided into 15 heating zones. The thermostat in each zone is set at 20.5 degree Celsius, the same temperature of the fresh air provided by the mechanical ventilation. The building is heated from 7:30 am to 3:00 pm on Monday to Thursday and from 7:30 am to 2:00 pm on Fridays.

诺顿公园拥有太阳能供暖系统来预热通风设备中的空气。该系统会将大厦南面屋顶板岩处的外部冷空气拖曳过来，屋顶石板会由于阳光的照射受热反过来对进入大厦的空气进行加热，一旦空气经过收集器通常会在进入大厦二层办公室之前被加热。

Norton Park has a solar heating system that preheats ventilation air. The system works by drawing cold air from outside under south-facing roof slates. The slates are warmed by the sun and in turn they heat the incoming air. Once the air has passed through the collector it is then conventionally heated before being distributed to the second floor offices.

外部进入的空气一旦从屋顶石板内拖曳进来将会立即和室内的空气温度进行对比。外部空气的温度平均会被增加 6 摄氏度且在晴天是太阳能收集器会将外部进入的空气增加差不多 20 摄氏度。

Norton Park has a solar heating system that preheats ventilation air. The system works by drawing cold air from outside under south-facing roof slates. The slates are warmed by the sun and in turn they heat the incoming air. Once the air has passed through the collector it is then conventionally heated before being distributed to the second floor offices.

室内用水

Water Consumption

为了实现室内用水量最小化，屋顶处的储水槽将集中收集雨水。随后储水槽中的水可部分用于冲洗厕所。

In order to minimize the use of water, rainwater from the roof is collected in a storage tank. It is then used as a part of water usage for flushing WCs.

照明和采光

Lighting and Daylighting

初始设计的阁楼限制了阁楼以下区域的采光。为了增强光照的同时防止光线太过刺眼，窗户的半处位置安装了遮阳板，遮阳板由建筑师设计制造。遮阳板由木制架子组成并安装在窗户中间的位置。可以通过手动调节遮阳板的角度来适当增加光线的亮度。为了增强采光亮度，屋顶的照明灯增加到 4 个。照明的设计符合节能的要求，同时允许通过调节转换将灯靠近窗户附近并实现与办公室内部照明控制系统分开。当在一个预先设置的期间内若监测到室内没有物体活动时，传感器将自动关闭每个办公室和会议室的电灯。电灯声控关闭系统的时间可以人为调节。

该大厦的能源管理应用建筑物能源管理系统（BEMS），该管理系统监控采暖和通风设备的运行。

The original design of mezzanines limits the access of daylight to some areas below them. Thus light shelves have been fitted halfway down the window in order to increase light and reduce glare. The light shelves are created by the architect. They consist of wooden shelves fitted halfway down the windows. Their angles can be altered by hand to increase light penetration. 4 roof lights were added to increase the level of daylight. The design of the lighting is energy efficient. Switches allow the lights closest to the windows to be controlled separately from those in the interior areas of the offices. Sensors automatically switch off lighting in individual offices and meeting rooms when nomovement has been detected for a set period of time. The time delay on the lights turning off can be adjusted. A Building Energy Management System (BEMS) is used to manage energy. It monitors and controls the heating and ventilation operation.

环保设计和环保产品

Environmentally friendly design and products

材料尽可能重复利用：

Materials are reused where possible:

- 从当地供应商购买产品从而降低运输成本和燃油损耗
- Products were to be obtained from local suppliers to minimise transport costs and fuel use
- 使用二手材料
- Second-hand materials were to be used
- 使用可再生木材和木制产品
- Timber and timber products were from sustainable sources
- 选择低耗能的建筑材料，例如用胶合木梁代替钢铁材料
- Construction materials with low embodied energy were selected, such as glulam beams rather than steel
- 避免使用将会引起室内空气综合症的产品，包括聚氯乙烯（PVC）
- Products linked with sick building syndrome, including PVC, were avoided
- 使用天然纤维地毯、漆布和水性涂料
- Natural fibre carpeting, linoleum and water-based paints were used.

该建筑将考虑装配易移动和可回收利用的建筑产品。同时，建筑设计有蝙蝠的巢穴来增强野生动物的多样性。

The construction has taken the easy removal and recycling of building products into consideration. Moreover, bat boxes are designed to promote wildlife diversity.

能源管理的结果

Energy Management Outcomes

该大厦曾在1999年雇用一位后勤经理，聘用该后勤经理后能耗律由原先的249千瓦时/年减少到了150千瓦时/年。能源使用所产生的碳排放量也从每年80公吨降低到50公吨。

A facility manager was appointed in 1999. The energy consumption was 249kWh/year before the appointment and it has been reduced to 150kWh/year. Carbon emissions associated with the energy use has also reduced from 80 to 50 tonnes a year.

成本和融资

Cost and Funding

翻新诺顿公园大厦的总成本为2，837，000英镑，相当于每平方米将花费756英镑。

The refurbishment of Norton Park Building cost a total of £2,837,000 including fees. This is equivalent to £756/m^2.

爱丁堡电话房

Telephone House, Edinburgh

背景

Background

电话房是在1973年建造的，该建筑用于

英国电信公司（BT）的电话交换台办公室。在二十世纪 80 年代末，为了兑现英国电信公司改进其能源的可持续利用性的承诺，该建筑得到翻新。

Telephone House was built in 1973. It was used by British Telecom (BT) as an office and telephone exchange. In the late 1980s, the building went through refurbishment due to BT’s corporate commitment to energy sustainability.

该建筑是一个十字型并同时拥有从中心地带延伸出的 2 个六层和 2 个七层的楼翼，可以在办公电子设备密集的电脑组件附近提供制冷设置。

The building has a cruciform shape with 2 six-storey and 2 seven-storey wings extending from a central core. The building provides cooling in the computer suite where there is a high concentration of office equipment.

建筑描述，设计和建造

Building Description, Design & Construction

采暖

Heating

屋顶机房装配了两个 586 千瓦的常规燃气锅炉。热水通过规定的线路通过周边对流散热器和加热器给整栋建筑物供暖。热度是由控制供水线路转换闸的室内温度传感器设定的。一个供暖分支负责给食堂空气搬运单位和一楼接待处的换流器供暖。补充区域的控暖和能通过 BEMS 系统远程单独操控已被证明是十分成功的。区域划分和具备灵活工作时间的相关程序的建立，可以避免之前该建筑对供暖 24 小时的需求。

Two 586kW conventional gas-fired boilers were introduced to the rooftop plant room. Hot water is delivered via zoned circuits to perimeter convector heaters throughout the building. Heat levels are set by room temperature sensors which control diverter valves in the water supply circuit. A branch distribution circuit provides heating for the canteen’s air handling unit, and for convectors in the ground floor reception area. Compensated zone control of the heating and the ability to isolate sections within each zone remotely by the BEMS has proved to be very successful. The zoning and associated programmer with flexible schedules have combined to avoid the previous need for the whole building to be heated at all times.

生活用热水

Domestic hot water

两个 87.6 千瓦 的直燃式煤气锅炉代替了原有位于屋顶装置房的水加热器来为该建筑提供生活用水，相同的直燃式煤气锅炉同样在一楼的厨房区域也有配置。两者的系统都不消耗集中供水储量。

Two 87.6 kW direct-fired gas boilers for DHW supply have replaced the original calorifiers in the rooftop plant room. Another, similar boiler is installed in the ground floor kitchen, and supplies DHW for this area. Neither system uses central hot water storage.

采光

Lighting

办公室的人造光线主要来源于天花板上的两个隐藏式灯管和四个荧光灯管组成，加上灯光较暗的灯组和桌上可个人控制的台灯。大部分办公室的中心区域和所有的厕所都有灯光较暗的灯组。

Artificial lighting in the office accommodation is mainly by recessed twin and quadruple fluorescent tubes, complemented by compact fluorescent down lighter units and desk lamps under individual control. The central access areas in most offices and all toilets have compact fluorescent down lighter units.

建设能源管理系统

Building Energy Management System

能源管理系统（BEMS）对建筑中所有的供暖、制冷和机械通风系统进行监控。该系统同时也应用在英国电信公司的其他苏格兰地区的办公楼中。

The BEMS monitors and controls all heating, cooling and mechanical ventilation systems of the house. It is also used for other BT buildings in Scotland.

成本

Cost

在 1990 年 10 月和 1991 年 9 月的监控期间内，该建筑消耗了 978，000 千瓦时的天然气和 140 万千瓦时的电力，分别花费了 10，232 镑和 66，704 镑，其中总电力的大约 31% 用于计算机室。

During the monitoring period Oct 1990 to Sep 1991, the building consumed about 978 000 kWh of gas and 1.4 million kWh of electricity, the cost of which was£10,232 and £66,704 respectively. About 31% the of total electricity is used in the computer room.

关于涉及能耗的方面，该建筑的天然气消耗要比典型的同种建筑要少很多。由于每个办公桌使用的都是微型计算机，电力消费稍稍超过“良好的实践水平“。

As for energy consumption, the gas consumption is considerably better than a typical office of this type. Due to the use of microcomputers on every desk, the consumption is slightly in excess of “good practice levels”.

供暖能源使用是 66.0 千瓦时每平方米。对供暖的适当控制以适应内部设备所产生的高热量，使得能源的使用较低。

Heating energy is 66.0 kWh/m². The application of appropriate controls to suit the high internal equipment heat gains contribute to this very low use of energy.

热水所消耗的能源是 66.0 千瓦时每平方米。该建筑的面积，决定了厨房和全年分布的电源操作所需的热能是很少的。

Hot water energy use is 66.0 kWh/m². It is considered a small use of energy for a building of this size with catering kitchens and distribution mains operational throughout the year.

办公设备所消耗的能源为 36.2 千瓦时每平方米。能耗只要来源于台式电脑打印机、绘图机、复印机、台灯和风扇。这些设备 24 小时全天都会打开。

The office equipment uses 36.2 kWh/m² of energy. The energy is generated mainly from desktop computers, printers, plotters, copiers, desk lighting and personal fans. These facilities are continually turned on 24 hours a day.

制冷负荷在大楼可用期间随着办公设备的增加而用量增加。制冷能耗为 7.1 千瓦时每平方米 。

The cooling load has increased with the increasedamount of office equipment during the life of the building. This 7.1 kWh/m² of energy consumption.

厨房餐饮的总耗能为 26.0 千瓦时每平方米。其中消耗天然气 18.9 千瓦时每平方米，消耗电力 7.1 千瓦时每平方米。高能耗的原因是大量的入住率和每周提供六天的热餐。

The cooling load has increased with the increasedamount of office equipment during the life of the building. This 7.1 kWh/m² of energy consumption.

采光照明的能耗为 28.0 千瓦时每平方米。由于电灯的设计和自动控制系统的有效利用，该能耗已经达到最优，整个建筑都安装了节能灯。该低能耗负荷，正是由于合理的人工、自动控制和良好的管理导致的。

Lighting consumes 28.0 kWh/m². It is considered a best practice of lighting efficiency because of lighting design and effective use of the automatic control system. Economical lighting is achieved by installing efficient luminaires and lamps throughout the building. This low installed power load is augmented by manual and automatic controls, and good management.

结论

Summary

每年可减少的总二氧化碳排放量为 19 千克每平方米，相当于 201，552 千克。实现低能耗主要原因是区域控制在最大程度上减少了内部供暖的耗能。当重新装修完成时，一个每年供暖和热水的成本为每平方米 73 分并拥有良好控制系统的建筑将会建成。所有的改进都将使得英国电信公司得以恪守其高效能源管理的承诺。同时，天然气成本下降超过 40 美元且照明的能耗已经超过了当下良好的标准。

The total saving of 19kg/m² of carbon dioxide is an annual saving of 201,552kg. The low energy consumption for heating and the effectiveness of zone controls to take full advantage of internal heat gains have been a major factor in this performance. In the completion of the refurbishment, a well-controlled building is created with annual heating and hot water costing 73p per square metre of treated area. All of these improvements are sustained by BTs corporate commitment to energy management. At the same time, gas heating costs is down by over £40 and electricity consumption for lighting exceeds current good practice target.

爱丁堡阿福科特小路周边

Advocate’s Close, Edinburgh

背景

Background

阿福科特小路周边位于爱丁堡老街的中心地带 - 王子街北部的边缘，这是一个曾经作为爱丁堡城市委员会的历史悠久的地段。该建筑超过 11 层楼，建筑的年龄从 16 世纪到 20 世纪中不等。老街建筑的人字纹图案是由和高街建筑的长期竞争而形成的，这些建筑建成于 16 世纪中期。需要改造的区域是阿福科特小路周边的中心位置，该位置处于在皇家英里和科伯恩路之前的狭小区域。

Advocate’s Close is situated in the heart of Edinburgh’s Old Town, on the edge of Princes Street Gardens, to the north. It is a historic site that was formerly occupied by the City of Edinburgh Council. Encompassing 9 listed buildings over 11 storeys, the site drops over 10 storeys from the top to the lowest level, and buildings range in age from 16th to mid-20th Century. The characteristic herringbone pattern of development in the Old Town evolved from the tight feuding of property fronting the High Street and was well established by the mid sixteenth century. The area that was under retrofit development is in the centre of Advocate’s Close, a narrow close from The Royal Mile to Cockburn Street.

建筑描述、设计和建造

Building Description, Design & Construction

为了保留原始建筑，该地点新增加一系列全新改造方案。这些新建筑将会融入进 16 世纪中期建造的老建筑中。

While retaining the existing buildings, a series of new quarters combining rehabilitation and alteration were designed to add to the site. This new series of new buildings are to integrate into the old buildings established by the mid sixteenth century.

新的屋顶阁楼代替了先前移除的上层楼层。新建筑和老建筑的建筑材料是相同的，外部材料使用乱石墙、琢石石雕、灰色粉刷和混凝土。所选的材料颜色统一了所有部件的颜色，新建筑将以浅黄色的石堆代替原有的灰色石堆，同时使用天然砂岩、板岩、深灰陶瓦外墙、木材和铝。原有的木梁和铸铁梁被移除，利用上百个钢梁来克服由于系统跟踪和滑轮所产生的超负荷物流问题，木梁同时被重新安排和利用于该建筑内。外部覆层为灰色铝的全新窗户代替了原有经过翻修的白色木制窗户。

许多外墙都得到了保留同时内部结构得到了修改、移除或替换了全新的钢制和混凝土框架。这些改动使一座两层楼山形墙建筑建造在老建筑之上。

Previously removed upper floors were replaced by new rooftop extensions. The building materials were chosen to unify different elements of old and new designs. External materials, such as exposed random rubble, ashlar stonework, grey render and concrete, were used. The material palette chosen unifies these disparate elements, replacing the grey render with a buff coloured render and using natural sandstone, slate, dark grey terracotta cladding, timber and aluminium for new building elements. Hundreds of steel beams were brought into the building to overcome over-sailing issues by a system of tracks and pulleys, a major logistical issue in itself. Existing timber beams and cast iron columns were removed. Timbers are then redressed and reused off site.New grey aluminium windows complement the surrounding cladding, in contrast with the existing timber windows, which were overhauled and repainted white. A number of existing facades were retained whilst the internal structure was modified or, removed and completely replaced with a new steel and concrete frame. This was necessary to allow a two storeys reinstated gable block with crow steps to be constructed above.

结论

Summary

该建筑改造是一个成功的在原有历史建筑基础上对建筑进行进一步的改造和调整的

一次成功的尝试，并延续了老街以往的建筑风格。此次改造增加了街道上的活动和人流量，特别是复兴路罗克斯堡法院地区。另外一栋可住 19 人的公寓在改造地区内的大卫博斯韦尔的房子附近建成，公寓在这片区域内十分热销。许多小型的工作室和顶层公寓在 2014 年内有 87% 的入住率。当地的社区获得了阿福科特小路周边所颁发的一系列建筑奖项，其中包括 RIAS 颁发的“苏格兰最佳建筑”且被形容为“以现代工艺构筑的复杂建筑”。

The retrofit develop is a successful new quarter combining rehabilitation of historic buildings and public realm with alterations and interventions which participate in the continuing organic architectural evolution of the Old Town. It encouraged street activity and pedestrian movement, especially at the revitalised Roxburgh’s Court. A further 19 serviced apartments were created in the adjacent Adam Bothwell House within the development. Apartments are flourishing in this area. Many compact studios and penthouse apartments experienced 87% occupancy rate in 2014. The local community rewarded the Advocate Close with a number of architectural awards, including the RIAS Andrew Doolan award for “Best Building in Scotland” where the judges described it as “urban weaving at its most complex”.

爱丁堡斯科顿楼

Scotstoun House, Edinburgh

背景

Background

斯科顿楼于 1965 年被英国奥雅纳工程顾问公司买下，在 1966 年以低层且单层的亭子类型办公楼的形式建成的。该建筑在围墙厨房花园的尽头处有办公室，同时将花园的另一边的尽头处的小屋和马厩被改造成植物房和守卫室。到 2005 年，该建筑有很多缺陷，例如太过狭小、通风条件差、只有一间会议室和缺乏必要设施 (如员工餐厅)。该建筑无多余的空间放置打印机，还需要附加装备式结构以扩大其库存能力。由于该建筑的结构是混凝土玻璃结构，工作人员在冬日会感觉十分寒冷在夏天会感觉过热。同时建筑的上方带有木镶板隔墙和天花板，建筑内部十分昏暗因此荧光灯需 12 小时全天开启。英国奥雅纳工程顾问公司在 2005 年任命 haa 将建筑改造并扩建成更符合可持续发展需求的建筑。

In 1965 Arup Scotland purchased Scotstoun House which subsequently (1966) was built as a low, single-storey, pavilion-like office building. The building has offices at one end of the walled kitchen garden while a cottage and stable at the other end were converted into a plant room and a caretaker’s house. By 2005, the space was cramped, poorly ventilated, had only one meeting room with limited facilities such as a staff kitchen; there was not enough room for printing equipment and a prefabricated structure had been tacked onto the building for archives storage. In the concrete and glass structure, the occupants were cold in winter and overheated in

室。

The objective was to the re-use the existing building and its ultimate conversion to meet present-day standards of energy use and environmental quality for its occupants. A creation of a simpler addition, connecting to the southeast face of the existing building and extending within the space of the walled garden was proposed and designed. The new extension continues beyond the former front face of the old building towards the North West, at this point utilising the old garden wall as its easternmost side. The bulk of the relationship between the old building and its parkland setting is therefore retained, as is the relationship between the old building and the setting of the walled garden. The height is similar to the 1966 building. An additional 625 m^2 of space was also created to accommodate new meeting rooms and breakout spaces.

summer; with the window blinds down almost continuously to protect its inhabitants from glare, heat or cold, and with its wood-panelled partitions and ceilings, the building was dark and the fluorescent strip lights were on for 12 hours every day. Arup Scotland commissioned haa in 2005 and decided to convert and extend the building with a sustainable design.

建筑描述，设计和建造

Building Description, Design & Construction

工程的目标是将原先的建筑改造成能符合现代能源使用标准和能让员工满意的高环境品质的建筑。其中，一个结构极其简单、同时连接已有建筑的南面和正在扩张的围墙花园的小路的设计正在筹划和准备。新扩建的部分建于老建筑的后面且位于西北面，在此处可以利用老花园的墙壁作为其东面的墙，老建筑之间的草地和围墙花园均得以保留。建筑的高度会在 1966 年的基础上继续增高。一个额外的 625 平方米的空间就会建造为会议室和休息

采光

Lighting

如上文所述，此工程的明确目标如下：给新老建筑尽可能引进足够多的太阳光照、创造良好的空气质量、制冷和通风管道遍布整栋建筑，同时降低供暖的气体排放和能源花费。除此之外阳光会通过全新建造的天窗照射进室内，超过 70 个太阳能导光管放置在新建筑的屋顶上，这些导光管可以直接将自

然光提供给工作区域。当自然光线等级低于400 勒克斯时，悬挂式低能耗荧光灯将被启用。
From the beginning, the project had specific aims of bringing as much natural light as possible into both the old building and the new extension, creating excellent air quality, cooling and ventilation through passive means throughout the whole building, providing a low-carbon source of heating and reducing energy bills and carbon emissions. In addition to the light coming into the building through the new clerestory windows around the new core, over 70 solar tubes (sun pipes) are fitted into the new roof to bring natural light directly into the working areas. Suspended low-energy fluorescent lighting is triggered to come on when natural light levels fall below 400 lux.

材料

Material

由于建筑的主要结构和外部墙面得以保留，扩建所需要的建筑材料得以减少。扩建利用了原有花园的一面墙，而花园的另一面墙由于部分损毁也被纳入翻新项目内。一部分损毁的建筑材料得以保存并用于填充路基。随后由于低成本效益该计划被废除，同时进行低碳技术的筹划。然而，建筑材料是根据绿色指南评级的要求选择的，老建筑中没有用到的一种新型铝材将会运用在新建筑的扩展中。铅作为一种新材料用于连接蓝色工程砖和老建筑外部边缘的软性材料。
New construction materials were reduced as the main structure and the external walls of the existing building were being retained and re-used. The extension utilised one of the existing garden walls, and part of another, which was partly demolished, stored and rebuilt as part of the redevelopment. On site materials were stored and crushed. They were then used for granular fill across the site and under road bases. Despite later been ruled out as not being cost efficient, low-energy technologies were proposed. However, materials were selected on the basis of a Green Guide A rating. A new capping made of aluminium to the old building is mirrored in the extension. Lead was a new material used as a softer material to tie in with the blue engineering brick on the exterior fringe to the old building.

采暖和通风

Heat and Ventilation

该建筑划分了 10 个采暖和通风点。植物房中的生物质能锅炉可以对水进行加热，整个建筑是完全自然通风的。原窗户的顶端均安装了新手动把手同时天窗的百叶窗帘会在室内温度超过设置的 2 摄氏度后自动打开。
The building is separated into 10 zones for heating and fresh air control. The biomass boiler in the plant room heats hot water. Ventilation is entirely natural in the whole building. New manual winding handles are fitted at the top of the old windows and louvers in the clerestory are designed to open automatically when temperature exceed settings by 2 degree Celsius.

老建筑中的隔热效果通过利用双层玻璃代替原有的克里托尔单层玻璃窗得以增加。由

于老建筑天花板上的高度限制，热式质量流量计通过一层 5 毫米的相变材料（PCM）安装在天花板的上表面缝隙中，当室内温度升高 PCM 材料会受热熔化并吸收储存热量。该材料会在夜晚温度降低时释放热量，同时回复至固体形态。该材料在此之前从未被使用过，使用之后提供了相当于 150 毫米混凝都所带来的热量。

Insulation has been increased in the old building through replacing all the old Crittall single-glazed windows with like for like double-glazed alternatives. Due to height restrictions above the ceiling in the old building, thermal mass has been added to this part of the building through the installation on the upper surface of the tongue and groove boarding of a 5mm layer of Phase Change Material (PCM). When the room temperature increases the PCM melts and absorbs and stores heat. It releases the heat when the temperature drops in the evening and overnight and the material returns to solid. Not used before in an office situation, this provides additional thermal mass that is purportedly equivalent to 150mm of concrete.

小屋经过翻修增加了淋浴、干燥棚和带锁储物柜，同时原有的会议室也得以升级改造。全新的生物质能锅炉和生物质成型颗粒燃料储藏点和后备燃气锅炉均放置在原有的植物室中，暖气管道仍然采用二十世纪 60 年代的管道。合同还额外要求在小屋的附近建造一个新的循环棚。

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控制系统

Control system

控制系统监控整座大厦的能源使用情况，其中包括温度、湿度、二氧化碳排放量和光强度等。

The control system monitors the energy performance of the entire building including its temperature, humidity, carbon dioxide and light levels etc.

结论

Summary

英国奥雅纳工程顾问公司已证实原始模型的准确性并预测全新的采光计划和过去的对比将每年节省 60% 的用电量，模型同时还预测采暖的成本将会降低 30%。

Arup have validated the accuracy of the original model that predicted yearly energy usage and demonstrated that the daylighting scheme is saving 60% of the electrical energy for lighting annually compared with the previous building. Modelling also predicts that heating costs will be reduced by 30%.

该项改造工程不仅符合 2008 苏格兰技术标准中的能源使用标准而且显著地超越了此标准。改造后的建筑获得了英国建筑研究院环境评估方法（BREEAM）的优秀等级和合同能源管理的 A 等级，原先的建筑得到极大的改善。

The project was subject to the 2008 Scottish Technical standards for energy usage, which were not only achieved but also significantly exceeded. The refurbished building achieved a BREEAM Excellent rating and EPC A-rating, an outstanding achievement considering the restrictions imposed by the original building.

生物质能的管理是由英国奥雅纳工程顾问公司自行管理，他们已经花时间优化了其运行管理，例如将燃烧生物质能锅炉在夜晚打开让热水充满缓冲罐为早上的分配做好准备。顾客同时也认同改造后的斯科顿楼是英国奥雅纳工程顾问公司的建筑典范。

The operation of the biomass is managed by Arup themselves, and they have taken time to optimise its operation, turning it on at night so as to fill up the buffer vessel of hot water ready for distribution in the morning. The client also acknowledges that Scotstoun House has re-established its place within the Arup oeuvre of quality architecture.

爱丁堡克雷米勒中心

Space Craigmillar, Edinburgh

背景

Background

克雷格米勒小学是在二十世纪 30 年代建造的，现在位于‘B’等级。随着学校在 1999 年关闭，其所有者卡斯罗 • 爱丁瓦在 2005 年翻新了该建筑，进而提供了 1,651 平方米的办公区域和 33 平方米的社区艺术剧院区域，此建筑经历了从小学到多功能办公和社区中心的功能转变。在二十一世纪初，一些翻新工作和内墙的隔热在建筑正面的不同地点进行，原有建筑的建造材料成分无从得知，因此此论文采用了建筑师的假设，此报告对该建筑的评论是基于此报告所用的图示做出的。

Craigmillar Primary School was built in the 1930's. Now 'Grade B' listed, and following the school's closure in 1999, the building was fully refurbished by owners CastleRock Edinvar in 2005, to provide 1,651m^2 of office accommodation and 337$m^2$of community arts and theatre spaces.The building underwent a change of use from a primary school to a mixed-use office and community centre, during early 2000’s, some refurbishment work was undertaken with the addition of internal wall insulation at various point across the front facade. The exact make-up of the existing building elements is not known, architect assumptions have been used and comments have been made based on drawings used in this report.

2012 年，爱丁堡龙比亚大学的苏格兰能源中心被要求确定该建筑有多少潜在保温性能提升的可能性。改造主要集中于两个房间，在此称为控制室和检验室。两个房间都在建筑物内占据着相同的地理位置、朝向和空间维度，房间彼此挨着且均位于二楼；每个房间都有一个 7.9 米乘 6.2 米的正门和四个 1.2 米乘 1.9 米的木窗；同时两室的供暖条件是相同的。分别安置温度记录器在两个房间内确定两者的供暖情况。

In 2012, the Scottish Energy Centre at Edinburgh Napier University was asked to identify potential thermal improvements that could be made to the building. It focusedupon two rooms, hereafter referred to as a control room and a test room. Both rooms occupy the same general location within the building, frontal orientation and room dimensions. The rooms are located beside one another on the first floor. Each room measures 7.9m by 6.2m with one main entrance and four 1.2m by 1.9m timber sash and case windows. To compensate for the difference in occupancy the control room was artificially heated to a similar level as that experienced in the test room. Temperature loggers were deployed in both rooms to validate the heat profile in the rooms.

建筑描述，设计和建造

Building Description, Design & Construction

窗户

Windows

控制室内和建筑正面的窗户均为单面的木制窗户，窗户在控制室改造时被翻新为更坚硬的、低辐射的中空玻璃且带有能打开的 uPVC 框架的窗户，中空玻璃是在室内组装的 - 与原有的玻璃之间大约存在 100 毫米左右的间隔。同时在中空玻璃之间安装了阻挡热辐射的百叶窗。

The windows in the control room are single glazed, timber sash and case and are representative of the windows all along the front facade.

The windows in the upgraded room were improved by the installation of a toughened, low emissivity secondary glazing unit, in an openable uPVC frame. The secondary units were installed internally, with an approx. 100mm air gap between the units and the existing windows. A radiant heat barrier and window blind were also installed, between the glazing units.

墙壁

Walls

在窗户上方的已有的南墙建筑的材料成分如下：500 毫米的预制混凝土过梁、75 毫米的不通风空隙、50 毫米矿棉绝热制品、12.5 毫米的位于 50 毫米金属框架上的石膏板。在窗户之下的南墙建筑由以下材料成分组成：25 毫米的毛坯外部渲染、230 毫米的固体砖砌、110 毫米的空洞，110 毫米的砖块，50mm 的不通风空隙、50 毫米的带有 12.5 毫米石膏板的螺柱框架。在翻新前北墙的建筑材料成分包括：25 毫米的毛坯外部渲染、90 毫米的固体

砖砌、110毫米的空洞、50毫米的不通风空隙、50毫米的带有12.5毫米石膏板的螺柱框架。在2006年建筑翻新时矿物保温层外加在外墙的内侧。

The existing make-up of the south wall construction, above the windows was: 500mm pre-cast concrete lintel, 75mm unventilated air gap, 50mm mineral wool insulation, 12.5mm plasterboard on 50mm metal framing. Below the window, the south wall construction consisted of: 25mm roughcast external render, 230mm solid brickwork, 50mm mineral wool insulation, 170mm unventilated air gap, 12.5mm plasterboard internal lining. The north wall construction, prior to any upgrades included: 25mm roughcast external render, 90mm solid brickwork, 110mm cavity, 110mm brick, 50mm unventilated air gap, 50mm stud framing with 12.5mm plasterboard. The mineral wool insulation was added to internal faces of the external walls during refurbishment in 2006.

建筑翻新之后，在南墙区域的悬挂式吊板上方的混凝土过梁和已有的矿物保温层直接额外增加了一层75毫米的大麻纤维绝缘层。另外，天花板也安装了100毫米的大麻纤维绝缘层，均在矿物保温层之间的上层部分。窗下的墙面区域同时安装了170毫米的钢丝芯保护层，该保护层安装在矿物棉和石膏板之间。

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北墙区域的空洞位置安装了钢丝芯保护层，同时天花板也安装了和南墙相同的大麻纤维绝缘层。

The north wall areas, had blown bead insulation pumped into the 110mm cavity, plus hemp insulation was laid between and above the joists at ceiling level as with the south wall.

测试方法

Testing Measurement

2012年9月24日同时在八个地点和两个房间内安装了U值测量设备。测量持续了两周，随后分析结果。测量的方法利用了完整的的Hukseflux热流传感器对案例研究进行细节分析。

U-value measurement equipment was installed in eight locations, across the two rooms on 24th September 2012. Measurements were taken for two weeks, then the results were analysed. The methodology used, followed a well-established format, using Hukseflux heat flux transducers as per the details in the full case study.

同时还进行了对房屋结构可见范围内的热量损失温度记录图的测量，该测量可以帮助确认在热绝缘和制冷中是否存在空隙。进行温度记录图测量时需要满足几个特定的条件，其中包括室内和室外的温差及天气条件。

A thermographic survey was also conducted, to display visually areas of heat loss through the building fabric. Thermographic surveys can help identify gaps in insulation or cold bridging. There are specific environmental conditions that are required to conduct a thermographic survey, including internal/external temperature differences and weather conditions. Download the case study document on the right for full details.

在原有的玻璃和后组装的第二块玻璃之间安装了中空温度探针，两侧中的其中一侧有保温层。

Temperature probes were installed within the space between the existing and secondary glazing units, two on either side of the heat barrier blind.

性能和效果

Performance and Results

U 值测量结果

U-value measurements

临时 U 值原位测量的结果表明，添加热屏蔽二次上光系统使得玻璃的 U 值得以改善，从 5.2 降为 0.6 W/m^{2}K，这些测量结果已和苏格兰能源中心所开展的其他翻新监测项目的测量结果进行对比，结果表明额外增加的热辐射屏障对结果没有显著的影响。

Interim results from the U-value in-situ measurements have shown that the addition of Thermal Shield secondary glazing system

improved the U-value of the glazing from 5.2 to 0.6 W/m^{2}K. These figures were comparable with measurements in other refurbishment monitoring projects carried out by Scottish Energy Centre. This suggests that the addition of the radiant heat barrier blind has had no significant effect.

窗户之间的空隙中设有温度探针测量热屏障两面的温差。结果显示热屏障的两侧温差增加显著且在下午4-5点时，热屏障两侧的温差达到最高峰。然而，所捕获的热量由于第二层玻璃的热性能原因，可能无法循环回室内。

Interim results from the U-value in-situ measurements have shown that the addition of Thermal Shield secondary glazing system improved the U-value of the glazing from 5.2 to 0.6 W/m^{2}K. These figures were comparable with measurements in other refurbishment monitoring projects carried out by Scottish Energy Centre. This suggests that the addition of the radiant heat barrier blind has had no significant effect.

为了测量‘控制’和改进建筑物的U值，悬挂式天花板的上方墙面上装有热流垫。测量结果表明，额外增加的大麻纤维绝缘层将U值从0.43W/m^{2}K降低至0.12W/m^{2}K。

Heat flow mats were installed on the wall areas above the suspended ceilings, to measure the 'control' and upgraded U-values of the fabric. The measurements indicated that the addition of the hemp insulation, improved the U-value from 0.43W/m^{2}K to 0.24W/m^{2}K. The area below the window was also tested and also demonstrated an improved thermal performance, with U-values reducing from 0.36W/m^{2}K to 0.12W/m^{2}K.

北墙的U值同样也从1.11W/m^{2}K降低到0.53W/m^{2}K。虽然U值得以显著降低，但最低值并未达到预期值。

The south wall U-value was also reduced, from 1.11W/m^{2}K to 0.53W/m^{2}K. While a significant reduction, this is not as low a value as had been expected. Reasoning for this is detailed in the 'lessons' section.

翻新墙面的温度记录图也同时显示从悬挂天花板上方和从下方窗户中损失的热量均有所减少。

Thermographic surveys on the control and upgraded walls also showed a reduction in heat loss from the areas above the suspended ceiling tiles, and below the windows.

结论

Summary

对偏远地区的墙面进行改造绝缘，出现了无法持续性保温隔热的问题。另外，北墙的保温性能没有预期中的效果提升。原因可能为由于短时间监测期所带来的不确定性，外部空气可能已进入空隙。温度记录图进一步确认了热量直接从悬挂式天花板下测的空气泄露渠道中损失，造成该结果的原因可能来自绝缘方面的连续性和研磨性问题。

Retrofitting insulation in isolated areas of wall presented issues with maintaining continuity of the thermal envelope. In addition, thermal performance on the north wall was not as improved as had been expected. This may be for several reasons, including uncertainties due to the short monitoring period, settling of the blown insulation or external air infiltrating the air gap. Thermographic images confirmed heat loss through air leakage paths directly below the suspended ceiling, which may result from a problem with continuity and lapping of insulation.

进一步的调查工作包括气密性测试，该测试会继续探索并解决这类问题。为了将不确定性误差降为 ±10% 的水平，将会开展长期的 U 值测试。总体而言，窗户的升级改造被证明是特别成功的。

Further investigative work, including air tightness testing will be conducted to explore and resolve these issues. A longer period of U-value testing will also be carried out, to reduce the errors to within the ±10% uncertainty level. Overall, the upgrades to the windows have been found to be particularly successful.

爱丁堡低碳创新中心

Edinburgh Centre for Carbon Innovation, Edinburgh

背景

Background

爱丁堡低碳创新中心（ECCI）是创建低碳经济所需的知识、创新和技术的摇篮。ECCI 由爱丁堡大学主办、赫瑞瓦特大学及爱丁堡龙比亚大学共同参与。该中心通过支持政府政策的实行，为提高企业创新能力提供专业的技能培训。

The Edinburgh Centre for Carbon Innovation (ECCI) is a hub for the knowledge, innovation and skills required to create a low carbon economy. Hosted by the University of Edinburgh, in partnership with Heriot-Watt University and Edinburgh Napier University, the ECCI supports Government policy implementation, enhances business enterprise and innovation and delivers professional skills training.

建造 ECCI 新大楼的工程从 2012 年的二月开始。此案例研究主要为将爱丁堡大学的旧高中校址改建为一个拥有创新区域、演讲厅、研讨室、展览馆和社交活动室的建筑。

Work began on the construction of ECCI's new premises in February 2012. This case study covers the refurbishment and remodelling of space in the University of Edinburgh’s Old High School in High School Yards to create an innovation suite, lecture theatres, seminar rooms, exhibition and social space.

建筑的改造工程遵从爱丁堡大学关于房地产和建筑的可持续发展策略，该策略包括对社会责任和可持续性发展的承诺，以及高于法律要求所需的环境标准。

Work began on the construction of ECCI's new premises in February 2012. This case study covers the refurbishment and remodelling of space in the University of Edinburgh’s Old High School in High School Yards to create an innovation suite, lecture theatres, seminar rooms, exhibition and social space.

该改造工程的目的是通过创建一个低能耗、高能源利用率的建筑来达到满足

BREEAM 关于‘优秀‘和‘杰出’水平的最低要求，ECCI 的建立会成为第一个被列入或被评为‘杰出’奖项的建筑。

The objective was to create a low energy and highly efficient building targeting a minimum BREEAM rating of ‘Excellent’ and an aspirational rating of ‘Outstanding’. The ECCI would be the first listed or refurbished building to be awarded 'Outstanding' if it is achieved.

建筑描述、设计和建造

Building Description, Design & Construction

构造

Fabric

ECCI 的改造工程包含对列入 B 类别建筑旧中学的改造和扩张。在 ECCI 建筑楼的旁边原先是两个 18 世纪的建筑，由于 18 世纪的建筑不复存在，一个在上层有会议 / 办公区域的全新咖啡馆建筑在此建立起来。同时，校园内课程和教学区域的广泛开放，也加强了附近的庭院间的联系。

The ECCI refurbishment project involved a major alteration and extension of the Grade B listed, Old High School. Where a pair of historic 18th century buildings had been lost, next to the rear ECCI building, a new café building has been created, with meeting/office spaces above. A generous opening within the lecture and teaching space reinforces a new connection to the adjacent courtyard.

建筑的主要结构和中庭及所有新建造区域连载一起，是一个交叉复合木材框架（CLT）和 CLT 楼板系统。据说 CLT 材料减少的二氧化碳排放量是其排放量的 4-5 倍。结构工程师对该建筑评估后决定先将结构型钢梁从内部移除，但并不排除存在可能再次将其用于支撑建筑内部的可能性。

The main structure, inserted within the atrium and all new construction areas, is a Cross Laminated Timber frame (CLT) and CLT floor panels system. CLT is said to lock in around 4-5 times more carbon than it takes to produce. The Structural Engineer assessed steel structural beams removed from the existing building; many could be reused as supports within the construction.

已有的 Cullaloe 和 Blaxter 石雕工艺已经得到了谨慎保守的修复。当地的石材十分耐用及易于修复。新建筑的上层结构主要被青铜涂层（含 80% 的铜和 20% 的锡）覆盖，是一种减轻负重的结构。同时这种图层材料也很耐用并且可回收。现有的框格窗得到了保留且根据附加的设计草案窗户得以全部维修，有些区域安装了一层较薄双层玻璃。深层符合木材钉有利于外部墙面的建造，内部区域的划分使用的是木钉。

The existing Cullaloe and Blaxter stonework has been carefully and conservatively repaired. The ‘base’ course to the new construction areas is also constructed in Cullaloe stone from Fife. Locally sourced stone is durable and repairable. The upper levels of the new construction are covered in bronze cladding (80% copper and 20%

tin). This is lightweight reducing demand on the structure. It is a durable and a recyclable material. The existing sash windows have been retained and repaired with additional draft proofing and the installation of slim line double glazed units in some areas.Deep composite timber studs support the external wall construction. The internal partitions are also timber stud.

隔热材料是由较有弹性的木制纤维和内部带密封层的硬质纤维板组成。蒸汽在外墙建造时是打开的，以允许湿气从大楼、墙壁的内部释出到室外。此举不仅对内部环境有所改善，同时也使大楼处于良好的状态。

Insulation is a combination of flexible wood fibre batts and rigid fibreboard with an airtight layer internally. The wall construction is vapour open, allowing moisture to move from both inside the building, and from within the wall construction, to the outside. This improves the internal environment and also the health of the construction.

室内装饰中的楼梯、天花板和许多墙面装饰的材料均为木材。其他楼层使用油毡（纯天然）和地毯。墙面粉刷采用的是水性漆，水性漆在蒸汽开放的时候具有高透气性能。

Internal finishes use timber for floors, ceilings and many wall linings. Other floors use linoleum (from natural sources) and carpets. Paint finishes are water based and have high breathability to work in conjunction with the vapour open external wall construction.

通风设备

Ventilation

该建筑主要采取被动的自然通风策略，空气换热器同时也给一些房间提供有限的冷气，制冷和换气只在人员密集度较高的房间内进行（例如演讲厅）。

The ventilation strategy is primarily passive natural ventilation. An air source heat exchanger also supplies limited chilled beam cooling to

some rooms. Cooling and displacement air are only in high occupancy rooms (e.g. lecture theatres).

采光

Lighting

建筑内部和外部的电灯均使用低能耗（包括 LEDs）节能灯，并装有区域控制和传感器来防止电能的过度使用。

Internal and external lighting is low energy (including LEDs) throughout, with zoned control and use of sensors to limit usage. Daylight studies were carried out at design stage to maximise natural light and reduce areas of summer overheating.

室内用水

Water

所有的卫浴设施均采用耗水量较低的设计。原先应计划安装一个雨水收集器，后来在一个十四世纪考古现场发现了一个储油罐，该储油罐可以改装成雨水收集器。建筑周边的植物景观同时用于控制和转移地表水。

All sanitary appliances are low water usage. Rainwater harvesting was intended to be installed, until 14th Century archaeology discovered on site inhibited the location of storage tanks. Permeable landscaping and an increase of soft landscaping are also used to control and divert surface water.

CHP

区域性的 CHP 系统用于提供暖气和用电。建筑后面的大楼屋顶的南面装有光伏板（占地面积 30 平方米）

A district CHP system is installed to provide heating and power. Photovoltaic panels (covering 30m²) were also installed on the south facing roof surfaces of the rear building.

第四章 模拟结果和融资机制
Chapter Four Modelling Results and Financing Mechanisms

4.1 主要假设

4.1 Key Assumption

如第三章所述，低碳建筑的选址具有一定的特点。根据邱在 2007 年的报告显示，此类建筑年能耗量在 70 到 300 千瓦时每平方米。此报告研发了一个以爱丁堡低碳创新中心（ECCI）的数据为基础的，为低碳改造技术评估经济效益的模型。在表格 4-1 和表格 4-2 中总结了由爱丁堡低碳创新中心相关报告的数据和一些基本假设。其中总成本为 610 万，合同期为 20 个月，总面积为 4790 平方米，经济年限假设为 50 年，天然气消耗的基线是每年每平方米 20 千瓦时，电力消耗，为每年每平方米 30 千瓦时，天然气消耗的基线为 127.4 千瓦时每年每平方米，电消耗为 56 千瓦时每年每平方米，碳排放的基线是每年 0.01 吨（ECCI, 2015），爱丁堡 2016 年当地的租金底线为每平方米 100 英镑。经过计算 2016 年的改造成本为每平方米 764 英镑。根据 ECCI 报告显示，低碳建筑改造被认为能带来将电力和天然气消耗降低 30% 等好处。

As illustrated in the Chapter Three, the design of low carbon buildings are site specific. According to research from Qiu (2007), the energy consumption in these building are 70-300kWh/m^2 per annum. The study develops a generic model for assessing the economic value of keeping the low carbon retrofit option open by using data from Edinburgh Centre for Carbon Innovation. Basic assumptions (e.g. building life, rental cost, discount factor and additional costs) and data calculated from ECCI reports are shown in Table 4-1 and Table 4-2. The total cost is GBP 6.1 million for 20 months of contract duration and the total area is 4790 m^2. The economic life assumption is 50 years. The baseline gas consumption is 127.4 kWh thermal per m^2 per year and the baseline electricity consumption is 56 kWh per m^2 per year . The baseline carbon emissions is calculation as 0.05 tCO_2 per year using conversion factors given by DEFRA .Carbon emission reduced to 0.04 tCO_2 per year after retrofitting. The baseline local rental cost at Edinburgh is GBP 100/m^2 in 2016. The retrofit cost is calculated from information above as GBP 764/m^{2}annually.

Table 4-1经济评估的静态假设

Table 4-1 Static Assumptions for Economic Assessment

静态假设 Static Assumptions	单位 Unit	价值
建筑 Building Life	年 Years	50
天然气消耗基线 Baseline Gas Consumption	千瓦时/平方米每年 kWh/m^2 per year	127.4
低碳建筑的天然气消耗 LCB Gas Consumption	千瓦时/平方米每年 kWh/m^2 per year	98
电力消耗基线 LCB Gas Consumption	千瓦时/平方米每年 kWh/m^2 per year	56
低碳建筑的电力消耗 LCB Electricity Consumption	千瓦时/平方米每年 kWh/m^2 per year	43
碳排放基线 Baseline Carbon Emissions	吨二氧化碳/平方米每年 tCO_2/m^2 per year	0.01
地租基线 Baseline Rental Cost	英镑/平方米每年 GBP/m^2 per year	100
改造成本基线 Baseline Retrofit Cost	英镑/平方米 GBP / m^2	764
折现率 Discount Factor		6%
额外建筑运营和维护成本（改造后） Additional Building O&M Cost (retrofit)	英镑/平方米每年 GBP/m^2 per year	0

经计算低碳建筑的改造成本在2016年为每平方米764英镑，同时学习率为20%（假设每降低20%的成本便可实现两倍的全球低碳建筑可容量）。初始全球低碳建筑可容量假设为120万平方米。初始市场租金（每年每平方米100英镑）假设将拥有3%的增长率，其中回复率为20%和标准差为5%。租金成本由ECCI的6种不同可出租的房间类型80%空间占有率计算而成。我们假设低碳建筑的初始租金比原假设高20%，即每年每平方米145英镑。我们同时假设天然气、电力和碳的价格为当地分别对应的市场价格。

The low carbon retrofit cost is GBP 764 / m^2 in 2016 with assumed learning rate of 20%, i.e. assuming 20% cost reduction per doubling of global capacity in low carbon building. The initial global low carbon building capacity is assumed as 1.2 million m^2. The initial market rent (GBP 100/m^2 per year) is assumed to grow at 3% with a mean reverting rate of 20% and a standard deviation of 5%.The rental cost is calculated using 80% occupancy rate of six different types of rooms and facilities in ECCI. Thus rental revenue is calculated as GBP 145/m^2 per year . We also assume the gas, electricity and carbon prices based on the local market environment.

Table 4-2 经济评估的随机假设

Table 4-2 Stochastic Assumptions for Economic Assessment

随机假设 Stochastic Assumptions	单位 Unit	基准值 Base Value	学习率 Learning Rate	漂移值 Drift	均值回复率 Mean Reverting Rate	标准差 Standard Deviation
低碳建筑的改造成本 LCB Retrofit Cost	英镑/平方米 GBP / m^2	764	20%			
全球低碳建筑可容量 Global LCB Capacity	平方米 m^2	1200000		3%	5%	3%
市场地租 Market Rent	英镑/平方米每年 GBP/m^2 per year	100		3%	20%	5%
低碳建筑地租 LCB Market Rent	英镑/平方米每年 GBP/m^2 per year	145		5%	20%	5%
天然气价格 Gas Price	英镑/兆瓦时 GBP/MWh	20		1%	50%	10%
电费 Electricity Price	英镑/兆瓦时 GBP/MWh	60		1%	50%	10%
碳价格 Carbon Price	英镑/吨二氧化碳 GBP/tCO_2	10		5%	20%	20%

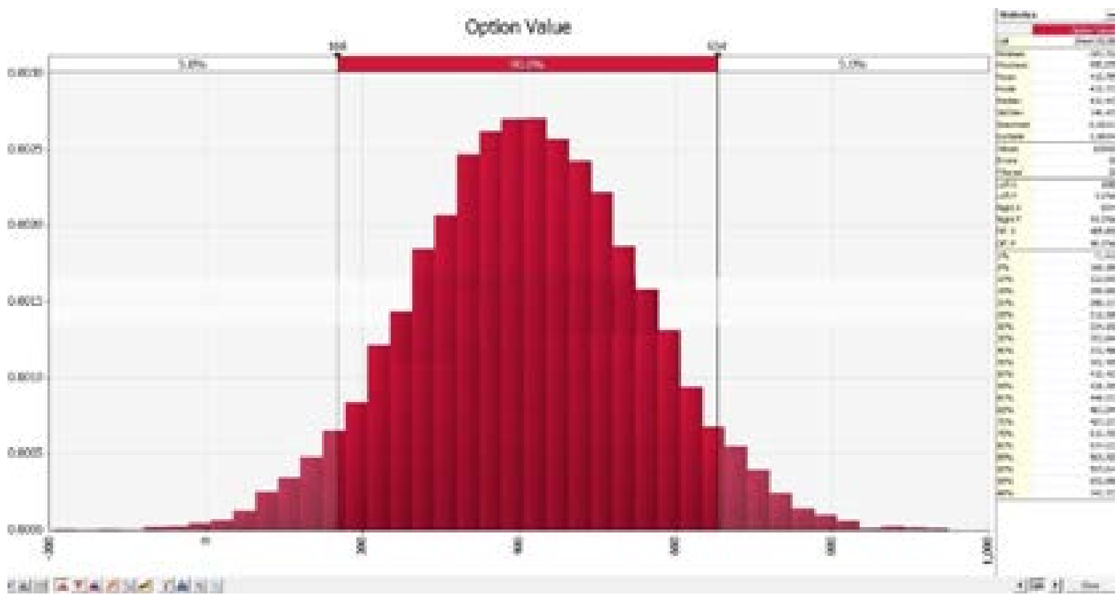

图4-1　模拟低碳改造技术的价值（10,000次试验）

Figure 4-1 Simulated Option Value for Low Carbon Retrofit (10000 trials)

4.2　结果

GBP/tCO_2

低碳建筑改造方案所带来的估计价值（图4-1）是每平方米 410.79 英镑。换言之，若一栋新建筑设计成低碳建筑可以在每平方米内增加 410.79 英镑的经济效益。不同改造方法的估计收益从负 193 英镑到正 950 英镑不等。低碳建筑改造将有 55% 的可能性将带来超过 500 英镑的收益。

The estimated option value of low carbon retrofit (Figure 4-1) is GBP 413.8per m^2. In other word, a new building if designed in low carbon retrofit readiness, could increase the economic value by GBP 413.8 per m^2. The estimated present value of option payoff ranges from negative GBP 103.5 to positive GBP 944.7. Approximately 75% chance, low carbon building retrofit will provide a higher than GBP 500 payoff.

4.3　情景分析

Figure 4-1 Simulated Option Value for Low Carbon Retrofit (10000 trials)

此研究报告测试了几种情景下的技术价值。若地租没有因为受到减少碳排放量和节能因素的影响而升高，改造方案的价值将大幅度减少至每平方米负 22.8 英镑（表 4-3）。若无燃料节能因素的影响，改造价值将下降为每平方米 379.02 英镑。初始改造的成本假设将影响整个改造方案的价值。当改造的初始资本成本增加至每平方米 1000 英镑时，改造方案的价值将会下降至每平方米 175.09 英镑。当改造的初始资本成本增加至每平方米 1100 英镑时，改造方案的价值将会下降至每平方米 75 英镑。当改造的初始资本成本增加至每平方米

1200 英镑时，改造方案的价值将为负。

The study tests a number of scenarios. If there is no rent increase benefit (i.e. only driven by carbon and fuel cost saving), the option value is dramatically reduced to negative GBP 19.9/ m^2 (Table 4-3). If there is no fuel saving benefit, the option value is reduced to GBP 378.92 /m^2. The initial cost assumption for retrofit influences the option value, when the initial retrofit capital cost is increased to GBP1000/m^2, the option value is reduced to GBP 177.44/m^2. If the initial retrofitting cost increase to GBP 1100 / m^2, the option value is further decreased toGBP 77.78/ m^2. When the initial retrofitting cost exceeds GBP 1200 /m^2, the option values renders a negative figure.

表 4-3改造价值情景分析的结果 (10,000次试验)
单位：每平方米
Table 4-3 Option Values of Scenario Analysis (10,000 trials)
unit: per m^2

进行低碳改造后租金无增加 No Rent Increase after LCB Retrofit	GBP -22.8
无燃料、电力和减少碳排放因素影响 No Fuel, Electricity and Carbon Saving Benefit	GBP 379.02
初始改造成本从 764英镑增加到1000英镑每平方米 Increase from GBP 764 to GBP 1000 /m^2 initial retrofit cost	GBP 175.09
初始改造成本从 764英镑增加到1100英镑每平方米 Increase from GBP 764 to GBP 1000 /m^2 initial retrofit cost	GBP 75
初始改造成本从 764英镑增加到1200英镑每平方米 Increase from GBP 764 to GBP 1200 /m^2 initial retrofit cost	GBP -24.9

4.4 重要启示

4.4 Key Implications

以上的分析给未来从事相关领域研究的人员和政策制定人员有以下几点初步的参考意见：

The generic analyses provide the following preliminary implications for future studies and policy makers:

- 爱丁堡进行建筑的低碳改造（在建筑的使用年限内）是具有巨大经济价值的。

-There is substantial financial value of retrofitting a building in Edinburgh to low carbon design captured over the lifetime

- 商业建筑改造成低碳设计的经济可行性在爱丁堡是非常高的。

-The economic viable chance of retrofitting a commercial building to low carbon design in Edinburgh is very high

- 目前租金增加所带来的效益是低碳改造的主要驱动力。

-The economic viable chance of retrofitting a commercial building to low carbon design in Edinburgh is very high

- 能授权使新建筑对低碳改造方案持开放态度和避免碳锁定效应的政策的颁布是至关重要的。

-It is critical to enable a policy to mandate new commercial building to keep low carbon retrofit options open and avoid the carbon lock-in effect

- 为商业建筑的低碳设计制定一个标准或模式是有益的。

-It is critical to enable a policy to mandate new commercial building to keep low carbon retrofit options open and avoid the carbon lock-in effect

参考文献

References

Abadie, L., Chamorrow, J.M., 2008. European CO_2 prices and carbon capture investments. Energy Economics 30, pp 2992-3015.

Alberth, S., 2008. Forecasting technology costs via the experience curve – Myth or magic? Technological Forecasting & Social Change 75, pp 952-983.

BRE (Building Research Energy Conservation Support Unit) (1995) British Telecom maintains office refurbishment improvements as part of its energy management programme. Available at: http://www.retrofitscotland.org/media/25848/brecsu-cs278-telephone-house.pdf(Downloaded: 20 Oct 2015)

BRE (Building Research Energy Conservation Support Unit) (2001) New practice case study 127 Norton park building, Edinburgh-feedback of designers and clients. Available at: http://www.retrofitscotland.org/media/22647/npcs-127_brecsu.pdf(Downloaded: 20 Oct 2015)

Climate Change Bill, 2009. Available at: http://www.scottish.parliament.uk/parliamentarybusiness/Bills/16147.aspx (Downloaded: 20 Oct 2015).

Climate Change (Scotland) Act, 2009. Available at: http://www.legislation.gov.uk/asp/2009/12/pdfs/asp_20090012_en.pdf (Downloaded: 20 Oct 2015).

Department of Energy & Climate Change (DECC), 2015. Digest of United Kingdom Energy Statistics 2015. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/450302/DUKES_2015.pdf (Downloaded: 20 Oct 2015).

Department for Communities and Local Government (DCLG), 2015. 2010 to 2015 government policy: energy efficiency in buildings. Available at: https://www.gov.uk/government/publications/2010-to-2015-government-policy-energy-efficiency-in-buildings/2010-to-2015-government-policy-energy-efficiency-in-buildings (Downloaded: 20 Oct 2015).

Dixon, T., 2014. Commercial property retrofitting. Journal of Property Investment & Finance 32 (4), pp 443-452.

EU Commission, 2010. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings, Official Journal of the European Union L153.

Fuss, S., Szolgayova, J., 2010. Fuel price and technological uncertainty in a real options model for electricity planning. Applied Energy 87, pp 2938-2944.

Fortin, I., Fuss, S., Hlouskova, J., Khabarov, N., Obersteiner, M., Szolgayova, J., 2008. An integrated CVaR and real options approach to investments in the energy sector. The Journal of Energy Markets 1 (2), pp 61-85.

Georgakaki, A., Gandhi, K., Kerr, N., Gouldson, A., Eames, M., 2013. Regional scale modelling on the potential of carbon emission and cost savings from retrofit of low carbon measures in the domestic sector of the Cardiff City Region. Retrofit 2050 Working Paper Number 2013/1.

IEA, 2015.Available at: https://www.iea.org/statistics/statisticssearch/report/?country=WORLD&product=balances&year=2013(Downloaded: 20 Oct 2015).

Kumbaroglu, G., Madlener, R., Demirel, M., 2005. A Real Options Evaluation Model for the Diffusion Prospects of New Renewable Power Generation Technologies. CEPE Working Paper No. 35.

Lee, S., Shih, L., 2005. Enhancing Renewable and sustainable energy development based on options-based policy evaluation framework: Case study of wind energy technology in Taiwan. Renewable and Sustainable Energy Reviews 15, pp 2185-2198.

Low Carbon Innovation Coordination Group (LCICG) 2012. Technology Innovation Needs Assessment (TINA) Non-Domestic Buildings Summary Report.

Mansfield, J., 2009. Sustainable refurbishment: policy direction and support in the UK. Structural Survey 27 (2), pp 148-161.

Marreco, J.M., Carpio, L.G.T., 2006. Flexibility valuation in the Brazilian power system: a real options approach. Energy Policy 34 (18), pp 3749-3756.

Markus, A. M., 1979. Building Conversion and Rehabilitation: Design for Change in Building Use. Newnes-Butterworth, London.

McArthur, J. J. and Jofeh, C. G. H., 2015. Strategic retrofit investment from the portfolio to the building scale: a framework for identification and evaluation of potential retrofits. Procedia Engineering 118, pp: 1068-1076.

McDonald, A., Schrattenholzer, L., 2001. Learning rates for energy technologies. Energy Policy 29, pp 255-261.

Myers, S.C., 1977. The determinants of corporate borrowing. Journal of Financial Economics 5, pp 147–175.

Perez-Lombard, L., Qrtiz, J. and Pout, C., 2008. A review on buildings energy consumption information. Energy and Buildings 40, 394-398.

Plantinga, A.J., 1998. The optimal timber rotation: An option value approach. Forest Science 44 (2), pp 192-202.

Qiu, B. C. 2007. Annual Report on China Building Energy Efficiency. China Architecture and Building Press. P. 240. (in Chinese)

Rothwell, G.A., 2006. A real options approach to evaluating new nuclear power plants. The Energy

Journal 27 (1), pp 37–53.

Rysanek, A. M. and Choudhary, R., 2013. Optimum building energy retrofits under technical and economic uncertainty. Energy and Buildings 57, pp 324-337.

Siddiqui, A.S., Marnay, C., Wiser, R.H., 2007. Real options valuation of US Federal Renewable Energy Research, development, demonstration, and development. Energy Policy 35 (1), pp 265–279.

Sullivan Report, 2007. Available at: http://www.gov.scot/resource/doc/217736/0092637.pdf(Downloaded: 20 Oct 2015).

Sullivan Report, 2013.Available at: http://www.gov.scot/resource/0043/00437438.pdf(Downloaded: 20 Oct 2015).

Szolgayova, J., Fuss, S., Obersteiner, M., 2008. Assessing the effects of CO_2 price caps on electricity investments – A real options analysis. Energy Policy 36, pp3974-3981.

Tan, B., Anderson, E., Parker, G., 2007. Managing Risk in Alternative Energy Product Development. Proceedings of the 25th International Conference of the System Dynamics Society and 50th Anniversary Celebration, 29 Jun – 2 Aug 2007, Boston. Available at: http://www.systemdynamics.org/conferences/2007/proceed/papers/TAN235.pdf(Downloaded: 20 Oct 2015).

The Edinburgh Centre for Carbon Innovation (2015) ECCI: The Edinburgh Centre for Carbon Innovation. Available at: http://www.retrofitscotland.org/media/22645/ecci.pdf (Downloaded: 20 Oct 2015)

Yang, M., Blyth, W., Bradley, R., Bunn, D., Clarke, C., Wilson, T., 2008. Evaluating the power investment options with uncertainty in climate policy. Energy Economics 30, pp 1933–1950.

Zhu, L., Fan, Y., 2011. A real options-based CCS investment evaluation model: Case study of China’s power generation sector. Applied Energy 88 (12), pp 4320-4333.