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Climate Ready Traditional Buildings at the University of Edinburgh

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Image: Old College
Source: [Brand Essentials](), The University of Edinburgh

Executive Summary

This report presents a qualitative analysis of a range of climate change adaptation case studies, with the aim of proposing a range of 'best practice' adaptation solutions to make traditional buildings at the University of Edinburgh (UoE) 'climate ready'. Based on discussions with the client, the Department for Social Responsibility and Sustainability (SRS) at UoE, the report includes a summary of climate change and adaptation, and the related risks and impacts, with regards traditional buildings at UoE. The main research question this study seeks to answer is:

> *"What climate change adaptation solutions exemplify best practice for UoE as it seeks to enhance the resilience of its traditional buildings?"*

The design of this study began with a combination of discussions with the client and researching secondary data and reports related to UoE, traditional buildings in Scotland and climate change adaptation. From this, a gap was identified whereby it appeared that UoE had no dedicated adaptation strategy specifically for its many traditional buildings and that weather-related damage repairs were predominantly conducted on a reactive basis and not as part of a proactive, planned adaptation approach. An analysis of relevant case studies was deemed an appropriate method in order to identify 'best practice' solutions and to provide some meaningful recommendations. The case studies were analysed using a multi-criteria approach in terms of applicability to the UoE context.

The overarching conclusion from this study is that in order to best enhance the resilience of its traditional buildings to the impacts from future climate change UoE should consider a wide-ranging approach that covers non-traditional buildings, landscaping and effective engagement and communication strategies, as well as the traditional buildings themselves. This study identifies a number of 'best practice' adaptation solutions that UoE should apply in order to achieve this. It also acknowledges that UoE has implemented some of these measures already. The study recommends that, given the importance of its traditional buildings to core operations and brand image, UoE should consider a more proactive approach to making its traditional buildings more resilient to a changing climate.

A number of limitations are deemed to have affected this study, including accessibility of data, access to key personnel within UoE internal departments and a general paucity of climate change adaptation case studies on traditional buildings. For example, the group had on a number of occasions engaged with UoE Estates & Buildings staff, as well as external climate change adaptation professionals, only to find all too often a lack of response. Ongoing academic union strike action was also felt to have hampered access to the client. Given the limited timeframe, these combined to have a significant impact on the timely progression of the study, though, it is hoped, not to the accuracy and relevance of its findings.

By way of a multi-criteria analysis of a range of climate change adaptation case studies, this report finds a coherent 'best practice' approach for making UoE traditional buildings more resilient to climate change. The findings herein will be of value to SRS in terms of both contributing to the draft adaptation strategy proposal and as a means of engaging with internal departments on these issues.

Table of Contents

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Social Responsibility and Sustainability

Acknowledgements

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Social Responsibility and Sustainability

List of Tables

List of Figures

1 Introduction

This report has been prepared for the Department for Social Responsibility and Sustainability (SRS) at the University of Edinburgh (UoE). The report considers climate change adaptation measures for traditional buildings within the UoE estate.

The Paris Agreement, which came into force in 2016, places significantly enhanced importance on climate change adaptation (UNFCCC, 2018). The United Nations Framework Convention on Climate Change (UNFCCC) defines adaptation as:

> *"Adaptation refers to adjustments in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. It refers to changes in processes, practices, and structures to moderate potential damages or to benefit from opportunities associated with climate change." (UNFCCC, 2014)*

Adaptation to climate change is vital in building resilience to existing and potential future threats and proactive planning can help early adopters realise benefits such as cost savings and business continuity, as well as an enhanced reputation (Adaptation Scotland, 2017). Such high levels of understanding and preparedness will require the collective ongoing efforts of actors across all areas of society (The Scottish Government, 2014), and, in doing so, those that take the lead will not only be addressing organisational risk, but may also stand to gain competitive advantage.

UoE recognises the significance of the climate change challenge and aims to build on its already world-leading expertise in this area (UoE, 2017a). This is demonstrated by the ambitious targets in its *Climate Change Strategy 2016-2026* (UoE, 2016a), which sets a vision for carbon neutrality across core operations and activities by 2040, and lays out a comprehensive whole institution approach to mitigation and adaptation, encompassing research, learning, teaching, operations and investments.

> *"The University will become more resilient, creating a sense of place on campuses and promoting well-being and biodiversity, as an integral part of the wider context of the City of Edinburgh." (SRS, 2017)*

As part of wide-ranging efforts, SRS is currently developing a climate change adaptation strategy designed to future proof UoE against changing climatic circumstances. The SRS draft adaptation strategy proposal (SRS, 2017) highlights the need to identify 'win-win' adaptation options for the University in terms of financing, reputation and improved physical resilience of its estate. A key part of developing such a comprehensive adaptation strategy is that the University consider its many traditional buildings and implement measures to enhance their resilience.

The aim of this study is to identify 'best practice' climate change adaptation solutions for the traditional buildings within the UoE estate. To this end, this study is guided by the research question: "What climate change adaptation solutions exemplify best practice for UoE as it seeks to enhance the resilience of its traditional buildings? This main research question is subdivided into 3 smaller questions:

- What climate change adaptation solutions have been or are being implemented on UoE traditional buildings?

- What is the scale and significance of future climate change for UoE traditional buildings?
- What is the range of climate change adaptation solutions appropriate for traditional buildings and are these relevant/applicable to the UoE context?

In order to answer these questions, firstly, section 2 provides the general background on climate change and adaptation at UoE. More specifically, it outlines the UoE context for (i) the historical impacts of climate change and any adaptation measures already implemented, and (ii) the likely future impacts from projected climate change and the key risks stemming from that. Section 3 then provides a definition for traditional buildings in Scotland and considers the significance of traditional buildings for UoE in both physical terms and in terms of brand image as an historical academic institution. Section 4 describes the methodology employed in approaching the main research question. Section 5 presents seven case studies, carefully selected for their relevance to achieving improved climate resilience for UoE traditional buildings. Section 6 provides conclusions and recommendations for UoE, as well as identifying this study's limitations and proposes ideas for further work and research.

2 Climate Change, Adaptation and Traditional Buildings at UoE

This section gives an overview of climate change, adaptation and traditional buildings at UoE. More specifically, it outlines observed and projected climate change in Scotland and describes how UoE has already been impacted by weather-related events, as well as any adaptation measures already implemented by UoE. It also considers how UoE is likely to be affected by future climate change and discusses the key risks and potential impacts that could arise. The section concludes with a definition for traditional buildings in Scotland and considers their significance for UoE in both physical terms and in terms of brand image.

2.1 Observed Climate Change in Scotland

Scotland's climate is already changing, and rapidly, characterised by warmer and wetter winters and warmer and drier summers. The last century has seen increased temperatures, sea level rise, changing rainfall patterns, increased frequency and unpredictability of extreme weather events and fewer days with frost and snow cover (Adaptation Scotland, 2018). Scotland's changes also reflect wider trends for the UK as a whole, whereby 8 out of the 10 warmest years recorded have occurred since 2002 and 7 out of the 10 wettest years recorded have occurred since 1998 (Met Office, 2017).

2.2 Observed Weather-related Impacts on UoE and Adaptation Actions Taken

These changes have already impacted many areas of Scotland's natural environment and society, including buildings and property, people and health, agriculture and forestry, transport, water and energy. UoE too has been impacted by weather-related events in recent years and has responded with some degree of adaptation action, as summarised in Table 1.

Table 1: Summary of Weather-related Impacts on UoE and Actions Taken (Source: SRS, 2017 & UoE Estates, 2016)

Observed impacts	Actions taken
Flooding - Kings Buildings campus	• Flood risk assessment undertaken for critical engineering infrastructure (electricity and heating supply) • Kings Buildings infrastructure project • Sustainable drainage systems
High winds - structural damage to buildings and trees	• Risk assessment of damage to buildings/infrastructure from fallen trees
Overheating - glass-fronted buildings in summer	• Intelligent design in new builds & refurbishment programs

2.3 Adaptation Action at UoE

Attributing the degree to which climate change is responsible for weather-related impacts (UKCP, 2014) is not without difficulty. Nevertheless, of the above impacts, flooding is one issue that has become more prominent in recent years as the climate has changed (SRS, anecdotal evidence)[1]. This has led to the development of a risk assessment for critical engineering infrastructure. The actions in Table 1 aside, however, it is important to note that UoE currently does not yet have a comprehensive flood risk assessment covering its entire estate (though this is scheduled to be in place by mid-2018).

[1] Anecdotal evidence from Dr Elizabeth Vander Meer, SRS

While the SRS draft adaptation strategy proposal (SRS, 2017) does highlight a number of existing and upcoming adaptation initiatives, for the purposes of the current study, it is important to note that UoE seems[2] to take a more reactive approach to building and property repairs where climate impacts are concerned and that there is currently either no dedicated adaptation strategy in place for protecting its traditional buildings (SRS, anecdotal evidence)[3].

2.4 Projected Climate Change for Eastern Scotland

The UKCP (2014) climate projections give an idea of how the climate for Eastern Scotland is likely to change in by the 2020s (2010-2039). The data in Tables 2 and 3 cover the climate variables most relevant to the UoE estate, and hence its traditional buildings: temperature and rainfall.

These data highlight the central estimates ('as likely as not') for the key changes for summer and winter respectively, as these two seasons most easily represent the full range of projected annual change. The data presented are for a high emissions scenario, in-keeping with global temperature rise projections based on countries' current emissions reduction contributions (UNEP, 2017).

Table 2: Key Climate Changes for Eastern Scotland in Summer (Source: UKCP, 2014)

Summer	
Key climate changes	Projected change ('as likely as not')
Change in mean temperature	+1.4°C
Change in mean daily maximum temperature	+1.8°C
Change in mean daily minimum temperature	+1.5°C
Change in temperature of the coolest day	+0.9°C
Change in temperature of the warmest day	+1.7°C
Change in mean rainfall	-4.0%
Change in rainfall on the wettest day	+2.5%

Table 3: Key Climate Changes for Eastern Scotland in Winter (Source: UKCP, 2014)

Winter	
Key climate changes	Projected change ('as likely as not')
Change in mean temperature	+1.1°C
Change in mean daily maximum temperature	+1.3°C
Change in mean daily minimum temperature	+1.3°C
Change in temperature of the coolest day	+1.0°C
Change in temperature of the warmest day	+1.0°C
Change in mean rainfall	+3.0%
Change in rainfall on the wettest day	+5.0%

These data show the degree to which summers are likely to become even warmer and drier and winters even warmer and wetter. Projections for changes in wind patterns and extreme weather events are difficult to model and are not presented here. This does not, however, preclude the potential for high wind and extreme weather events. Indeed, Scotland is expected

[2] Repeated attempts by the group to obtain information and/or arrange a meeting with UoE Estates & Buildings were, sadly, unsuccessful. The group did, however, manage to obtain the Infrastructure Flood Risk Assessment for critical infrastructure and Estate Age and Listing Status documents.
[3] Anecdotal evidence from Dr Elizabeth Vander Meer, SRS

to see increases in summer heat waves, extreme temperatures, drought and more frequent and intense extreme wind and rainfall events (Adaptation Scotland, 2016). The risks for, and potential impacts on, the University are many, and they too are expected to increase and intensify.

2.5 Climate Change Risks and Potential Impacts on UoE

The consequences of future climate change have the potential to impact across all UoE operations and activities. This includes both direct and indirect impacts subdivided into four key areas of risk: physical, regulatory, financial and reputational – see Table 4.

Table 4: Key Risks and Potential Impacts on UoE from Future Climate Change

	Key risks	Potential impacts
Direct	**Physical**	• Fail • Increased flooding • Changes in heating/cooling balance • Water shortages from summer droughts • Damage to property/services • Disrupted operations • Injury to students/staff

Indirect	**Regulatory**	• Failure to meet statutory obligations
		  ○ Legal challenges
		  ○ Financial sanctions
		  ○ Operational sanctions/restrictions
		  ○ Reputational damage

	Financial	• Reduced revenue from decreased student enrolment
		• Reduced revenue from decreased international collaborations
		• Reactive approach to adaptation likely to cost more:
		  ○ disruption to normal operations
		  ○ property/services downtime
		  ○ contingency measures
		  ○ unplanned repairs
		  ○ compensation claims
		  ○ higher insurance premiums

	Reputational	• Low physical resilience could lead to:
		  ○ decreased student enrolment
		  ○ decreased international collaborations
		• Lack of action could result in:
		  ○ failure to meet institutional goals and stated climate change mitigation/adaptation targets, leading to:
		  ○ damage to brand and reputation

2.5.1 Physical Risk

The main physical risks to UoE will come from increases in temperature and rainfall.

The average daily temperature is likely to rise by 1.8 °C by the 2020s – see Figure 1 - which, though seemingly insignificant in and of itself, means that the temperature baseline will shift upwards and that future teperature extremes will be higher again. Heatwaves are also likely to become more frequent.

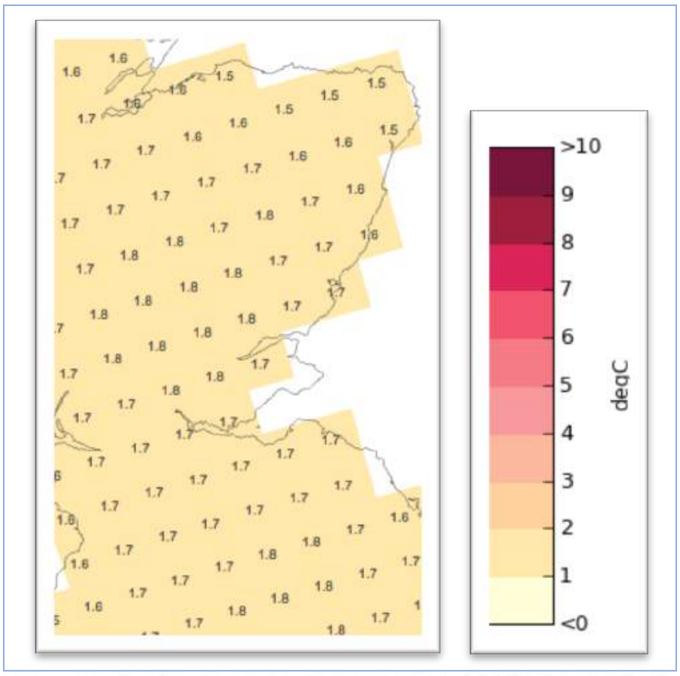

Figure 1: Maximum daily average temperature increase (°C, 'as likely as not' under a high emissions scenario, source: UKCP09)

Such events have the potential to cause harm to individuals and property, as well as materials and equipment therein. For UoE, a large academic institution with around 35,000 students, 13,000 staff, over 700 buildings, and with a range of important and delicate artefacts and expensive, sensitive scientific equipment in buildings across its estate, temperature rise will be a major concern. This may lead to a greater need for space cooling, which could have ramifications for energy efficiency and emissions reduction initiatives.

The SEPA (Scottish Environment Protection Agency) Flood Maps provide a visual representation of some impacts already felt by UoE, showing areas currently likely to be at risk of flooding. Figure 2 illustrates the likelihood of flooding for (i) The Meadows, which sits adjacent to the main George Square campus, (ii) King's Buildings campus, (iii) Little France campus and (iv) sports facilities at Peffermill. The purple areas represent surface water flooding, while the blue areas represent river flooding.

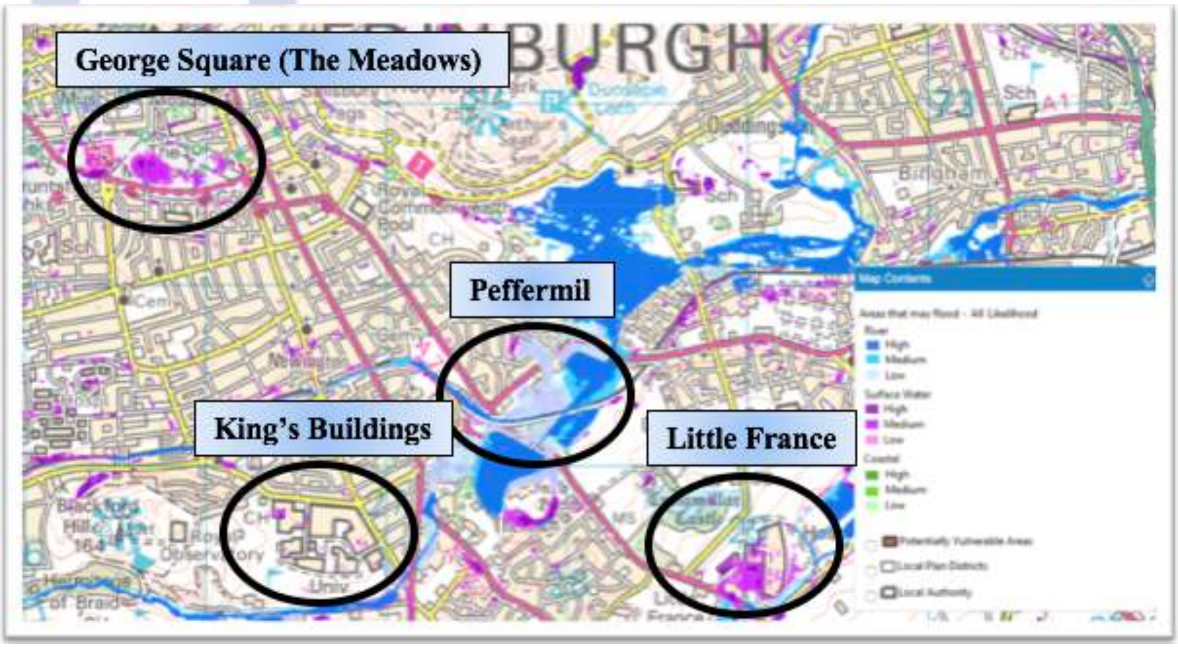

Figure 2: Flood Map Showing the Likely Surface Water & River Flood Risk for George Square, King's Buildings, Little France and Peffermill (Source: SEPA, 2015)

Surface water flooding is the main concern, with the Meadows currently at medium risk. This has the potential to adversely affect the Main Library and buildings on or near Buccleuch Place, including the Institute for Advanced Studies in the Humanities (IASH) and the International Student Centre (ISC). Major projects at the design stage in this area include the Edinburgh Futures Institute – Quartermile (£119m) and new Student Centre (£82m), both of which will potentially impact on, and be impacted by, future surface flooding in this area.

On the King's Buildings campus, the Weir Building and UK Biochar Research Centre are at high risk, with the Alexander Graham Bell Building, William Rankine Building and Fleeming Jenkin Building all at medium risk. The planned Murchison House Refurbishment programme (£14m), in the north-east corner of the campus places it at high risk, though this should be mitigated somewhat by the KB Infrastructure Project [Phase 1] (£13m).

The Little France area, which houses the Queen's Medical Research Institute (QMRI) and Edinburgh Imaging Facility RIE, is at medium risk, as is the currently-under-construction Institute for Regeneration and Repair (£54m). There is also a low-high risk of river flooding for the Peffermill playing fields and surrounding area.

2.5.2 Regulatory Risk

At the national level, UoE, as a public-sector organisation, is bound by statute under The Climate Change (Scotland) Act 2009 (The Scottish Government, 2011a) to act in ways that contribute towards delivery of the Act's emissions reduction targets and to deliver any statutory adaptation programme considered most sustainable. The Scottish Government (2014)'s Climate Change Adaptation Programme further requires all public bodies to conduct business in ways that will help deliver climate change adaptation as stipulated in the Climate Change Act, and identifies major roles for Scotland's public bodies in building, influencing and supporting the resilience of individuals and communities to the impacts of climate change. This is further emphasised in Scotland's Climate Change Adaptation Framework (The Scottish Government, 2009), which states that:

> *Scotland's public sector has a central contribution to make in helping Scotland build its resilience to a changing climate: through the development of evidence and research, provision of guidance and services, delivery of adaptation measures and through direct management of built and natural estates.*

Key to delivering these outcomes are information and awareness. Public Bodies Climate Change Duties: Putting Them into Practice (The Scottish Government, 2011b) stipulates that any adaptation planning process include raising awareness of climate change both internally and externally. Another key part of the process is reporting, which is a mandatory annual requirement for public bodies through completing their Public Bodies Climate Change Duties Report.

2.5.3 Financial & Reputational Risk

While difficult to quantify, financial and reputational risks are very real concerns for UoE, as summarised in Table 4. These risks stem primarily from inattention to the physical and regulatory risks related to climate change adaptation and could have far-reaching financial and reputational consequences for UoE. Financial risks relate predominantly to reduced revenues due to disruption to normal operations and/or impacts on personnel. Such disruptions, if they result from insufficient or inappropriate adaptation action, are likely to be closely linked to expenditure on such adaptation action(s), which will require careful consideration as the exact impacts from future climate change are still uncertain. Reputational damage would follow on from this and most likely have a compounding and overall negative effect.

2.6 Traditional Buildings

2.6.1 Traditional Buildings in Scotland

Traditional buildings in Scotland are generally considered to be those of solid wall construction built before 1919. Such buildings are generally resilient but can be vulnerable to the stresses brought about by a changing climate if they have been improperly altered or neglected. Increases in temperature, rainfall and extreme weather events are of particular concern, all of which can contribute towards accelerated decay of the building fabric as well as adversely affecting the internal conditions for the occupants (HES, 2017).

Equally important as any particular traditional building itself is the immediately surrounding area, which can play a key protective role by, for example, diverting water away from the building and into designated drainage or catchment areas. Landscaping measures and neighbouring buildings - traditional or otherwise - are also therefore vitally important in any approach that seeks to protect traditional buildings (HES, 2017).

Due to their very specific nature, traditional buildings are often subject to special conditions. For example, they are often listed or situated within conservation areas, meaning that special consent may be required for any alterations to the building either externally or internally. If a building is listed, Listed Building Consent must be obtained where proposed works or alterations, either external or internal, will alter the character of the building. Such consents and permissions are granted by Historic Environment Scotland or the local authority - in this case, the City of Edinburgh Council – or both (HES, 2017).

Traditional buildings therefore present a very particular case for a number of reasons. They may be particularly vulnerable to a changing climate if not properly maintained. Such maintenance is not restricted to the buildings themselves, but also extends to the surrounding area, including landscaping and neighbouring buildings and structures. They are also very often subject to specific constraints concerning alterations, whereby any adaptation actions may be subject to prior approval from the relevant authorities.

2.6.2 Traditional Buildings at UoE

Traditional buildings make up a considerable proportion of the UoE estate of 728 buildings (UoE Estates, 2018a), with many of these buildings performing key functions in terms of learning, teaching, research and administration – see Table 5.

Table 5: UoE Traditional Buildings (Source: UoE Estates, 2018b)

Traditional buildings (pre-1920)	**Total number**	110
	% of UoE estate	15%
Building Listing Category	**A**	16
	B	56
	C	6
	N/A	32

Many of these buildings also play a very important role in the brand image of UoE as an historic and world-leading academic institution, e.g. Old College and McEwan Hall, both of which are used regularly in UoE publications, promotions and high-profile events (UoE, 2017b & UoE, 2018) - see Figure 3.

 *Image source: UoE, 2016b*	**Building name**	Old College
	Year Built	1789
	Function	Learning Teaching Research Administration Public events
 *Image source: UoE, 2016c*	**Building name**	McEwan Hall
	Year Built	1887
	Function	Graduations Exams Public events

Figure 3: Traditional Buildings Important to UoE Operations and Brand Image (Source: UoE Estates, 2018a)

UoE has suffered weather-related damage in the recent past and has undertaken some actions to remedy the situation and to prepare for future impacts. Increases in temperature and rainfall are the main physical climate risks that UoE will need to guard against and the Climate Change Strategy and draft adaptation strategy proposal go a long way to mitigating such risks.

Traditional buildings comprise a sizeable proportion of the UoE estate, as well as representing some of its key assets, and these buildings are vital to core operations and to the UoE brand image. These buildings will be especially at risk from a changing climate, not least because of their age but also because of the various restrictions and permissions that may apply to potential adaptation solutions.

This section has outlined the context for UoE traditional buildings regarding climate change impacts. This section has also identified a gap: a current lack of a dedicated adaptation strategy focusing on traditional buildings. The remainder of this study will focus on identifying adaptation best practice for UoE traditional buildings, collated from a range of carefully selected case studies, and will thus contribute towards filling this gap.

3 Methodology

This study applied a multi-criteria analysis to a range of case studies with the objective of identifying best practice for the protection and adaptation of UoE traditional buildings. As demonstrated in the introduction, the current climate projections for Scotland identify several threats to traditional buildings on campus. Moreover, landscaping measures and neighbouring buildings - traditional or otherwise - are also vitally important in any approach that seeks to protect traditional buildings. Based on this understanding, case studies from multiple sources were considered, including Historic Environment Scotland (HES) Refurbishment Case Studies, Climate Just, UK Climate Impacts Programme (UKCIP) and the European Climate Adaptation Platform (ECAP).

3.1 Case Study Appraisal

The full range of potential case studies were narrowed down to the 15 most relevant and applicable with a focus on traditional buildings, non-traditional buildings and landscaping, as well as 2 studies addressing the importance of stakeholder engagement and communication (see Appendix A). These 17 case studies were then arranged into a six-box format (Figure 4), providing a brief summary and analysis.

Challenges	Solutions	Significance	Cost and Benefit	Photo
• Public space need hard surfacing. • Hard surfacing causes high speed of rainwater runoff and flood risk. • Having potential challenge to keep the landscape and historic feature.	• Using gravel or other permeable material that design the hard surfacing to be permeable. • Building area filters that go through the permeable paving, underground chamber and finally the drains.	• Both maintained hard surfacing to keep functioning and made adaptation to climate change. • The process helps to clean the water and reduce the runoff rate especially heavy rainfall that help reduce the pressure to drainage system. • Not only no impact on historic features of buildings, but also make this place more attractive.	• Unknown for this case • Permeable pavers per square foot range from $4.00-$6.00. (vary with the availability of using material)	 **Applications to UoE** • Due to the difficulties of making huge change on listed building itself, using permeable pavement may be a good way to transform the outside environment of listed buildings, which can help to prevent flooding risk but also building more comfortable places.

Figure 4: Example of Six-box Format from Full Case Study List

3.2 Case Study Analysis

A multi-criteria analysis (Figure 5) was used to assess the case studies. In order to offer a reasonable comparison and provide a standardised analysis, a total of 9 criteria were applied (DCLG, 2009) and common features of the solutions abstracted from the cases. For better understanding they were then allocated into 3 key areas: implementation phase, operational phase, and sustainability. A 3-level rating system - low/medium/high - was then applied to the criteria within these key areas, with each level assigned a score of either 3, 2, or 1 point(s). The criteria under sustainability each scored 3 points.

Category	Case study	Climate variable	Action	Implementation phases									Operational phase					Sustainability potential			Points	
				Disruption			Time period			In-house (I) /external contractor (E)			Ongoing maintenance			In-house (I) /external contractor (E)		Energy efficiency gains	Emission reduction	Cost saving	Action	Case study
				L (3)	M (2)	H (1)	L (3)	M (2)	H (1)	I (2)	E (1)		L (3)	M (2)	H (1)	I (2)	E (1)	(3)	(3)	(3)		
Traditional	Case study 2		Roof rainwater harvesting	✓			✓				✓			✓		✓				✓	14	14

Figure 5: Case Study Analysis Matrix

As shown above, the actions from each case study were marked separately and then added up for each case study which gave the comparability among the cases. Note that because of the different nature of the case studies, the matrix only applies to the 15 studies related to traditional buildings, non-traditional buildings and landscaping, and not to those focusing more on engagement and communications. See Appendix B for criteria definitions and Appendix C for the full matrix covering every case study analysed. Based on this analysis, the 5 top-scoring case studies along with 2 communication case studies were selected (Table 6) to give a more detailed interpretation and relate them to the context of UoE.

Table 6: List of 7 Case Studies Selected for Case Study Analysis

Category	Case study
Traditional building	Case Study 1 - 19th Century House Refurbishment (UKCIP, 2009)
	Case Study 8 – Hot Mixed Mortar Re-harling and Adapting a Gable-end Wall (HES, 2016a)
	Case Study 14 – Five Tenement Flats, Edinburgh (HES, 2016b)
Non-traditional building & Landscaping	Case Study 11 - Supporting Implementation of Climate Adaptation Measures (ECAP, 2018a)
	Case Study 13 - Implementation of Green Urban Infrastructure Strategy (ECAP, 2018b)
Communication	Case Study 9 - Building Community Resilience to Flooding (Climate Just, 2014)
	Case Study 10 - Climate-Proofing Social Housing Landscapes (ECAP, 2018c)

Furthermore, a simplified analysis matrix (see Table 7 for an example) is presented for each case study in the analysis section of this report. For ease of understanding, criteria are summarised into the 3 key areas relevant to their adoption as adaptation measures - implementation phase, operational phase, and sustainability – providing clear information on how effective the various actions are.

Table 7: Simplified Case Study Analysis Matrix

Climate Variable	Actions	Implementation phase (max. 8)	Operational phase (max. 5)	Sustainability (max. 9)	Points total (max. 22)
	Solar shading	7	5	9	21
	Natural ventilation	7	5	9	21
	Mechanical ventilation	6	3	9	19

4 Case Study Analysis & Findings

The case studies presented herein comprise examples of best practice that can be readily applied to the UoE situation. Where relevant and known, past, present and future undertakings along similar lines by UoE are acknowledged. The case studies have been carefully selected on the basis of presenting a range of solutions all scoring highly in terms of the 3 key areas in the multi-criteria analysis: implementation phase, operational phase and sustainability (see Appendix C). They are presented in 3 sub-sections according to category: traditional buildings, non-traditional buildings & landscaping, and stakeholder engagement & communications. Each sub-section concludes with an assessment of the relevance of the studies for UoE.

4.1 Traditional Buildings

4.1.1 Case Study 1 - 19th Century House Refurbishment

Case Study 1 comes from the UKCIP (2009) and describes the case of a 19th century house showing the refurbishment of traditional buildings designed to tackle the overheating issue.

The buildings in this case studies were notably poor at regulating indoor temperature, mainly due to a lack of sun shading and poor ventilation control. Therefore, external solar shading and ventilation were the main solutions adopted. The actions are summarised in Table 8.

Table 8: Case Study 1 - Summary of Actions

Actions	Description
Solar shading	• Energy saving by decreasing the amount of energy need for cooling. (energy saving bill can payback the cost within 10 years) (Carbon Trust, 2010) • Improving indoor comfort for people working or staying (ESSO, 2018) • External blind has little disruption to the building users (Mark, 2012) • It is easy to be operated and maintained by occupants
Ventilation	• Health benefit • Reduce temperatures • Energy efficiency

The significance of this case study is that the types of buildings therein are similar to some UoE traditional buildings, thereby offering UoE the possibility to apply the same solutions.

Application to UoE

In the analysis matrix for case study 1 (Table 9), solar shading and natural ventilation received higher scores, so should be considered for the UoE adaptation plan. It should be noted that UoE has already adopted these measures on some newer buildings, e.g. the Arcadia Nursery and the Alexander Graham Bell Building (formerly the IDCOM Building) – both located at the King's Buildings Campus – have employed natural ventilation and external solar shading respectively (BREEAM, 2018).

Table 9: Case Study 1 - Simplified Analysis Matrix

Climate Variable	Actions	Implementation phase (max. 8)	Operational phase (max. 5)	Sustainability (max. 9)	Points total (max. 22)
	Solar shading	7	**5**	**9**	21
	Natural ventilation	7	**5**	**9**	21
	Mechanical ventilation	6	3	**9**	19

For traditional buildings however, UoE will need to strike the right balance between the buildings' appearance and effective adaptation solutions. Even though solar shading and ventilation are effective ways to address overheating, it is not straightforward to adopt these methods, given the aforementioned restrictions that apply to traditional buildings. Therefore, the feasibility of these actions and future expectations for UoE are discussed below.

External solar shading is very likely to change the appearance of a building (Coolbricks, 2011), though UoE can still consider some options for its traditional buildings, as shown in Figure 6. For example, overshadowing by urban design and vegetation is not applied to the building itself and horizontal beam overhangs which have different kinds of styles can fit into different kinds of buildings. Choosing the right materials and design will be key and may make these possible for use on traditional buildings.

Overshadowing by urban design and vegetation

Horizontal beam overhangs

Image source: UKCIP, 2009

Figure 6: Solar Shading Options

The other options from this case study are natural and mechanical ventilation, which can be adopted either in isolation or as a combined measure incorporating both. In order to make the most appropriate recommendation for UoE, several issues must be considered. Firstly, overheating is not likely to be as serious an issue in Edinburgh as in other parts of the UK (Hacker *et al*, 2005), meaning that more 'gentle' forms of ventilation may suffice. Secondly, retrofitting mechanical ventilation systems in/on traditional buildings, e.g. installing ductwork and piping, can damage the building fabric (Hunt, 2018). Therefore, UoE should first consider adopting simple natural ventilation its traditional buildings. The exact measures implemented will depend on the building in question: natural ventilation or mechanical ventilation or a combination of both. The relative benefits of natural ventilation are that it is easier to manage and costs less, though there may be security concerns and it may be less efficient in winter.

In conclusion, UoE should consider adopting solar shading and natural ventilation measures for traditional buildings to address the problem of overheating.

4.1.2 Case Study 8 – Hot Mixed Mortar Re-harling and Adapting a Gable-end Wall

In this case study from the Historic Scotland publication series: Refurbishment Case Studies (HES, 2016a), the building examined is a great piece of Georgian architecture built around 1754, listed as category A, and located in the north west of mainland Shetland.

The classically-proportioned Laird's house had suffered damages from strong winds and downpours which led to water penetration and severe damp problems. As mentioned in the introduction, Scotland is expected to experience a shift in weather conditions including hotter summers, wetter and warmer winters and more intense storms and downpours, and, because of the northern location of Shetland, these issues would only be amplified and incur greater damages. The actions implemented are summarised in Table 10.

Table 10: Case Study 8 - Summary of Actions

Actions	Description
Re-harling	Refurbishment team applied a **specially designed mortar** combined with traditional techniques to protect the south gable end wall
Lime washing	The new coating was lime washed to increase weather resistance and cope with driving rains
Restore chimney and flashing	The chimneys, flashing and drip details were restored and improved with better detailing
Repoint skew copes and other weathering details	
Double-glazed windows	The windows were deemed beyond repair thus replaced with replicate slim profile double glazed sash and case units in order to both solve water ingression problem and enhance thermal performance.

After several inspections, the various actions proved effective. The south gable end wall no longer suffered from obvious water penetration during heavy rain and dampness had reduced evidently according to moisture monitoring. Overall, the listed building was deemed to have been coping adequately with driving rain and strong winds after the refurbishment.

The significance of this case study for UoE is that it provides a good example of adapting a listed building to a changing climate and demonstrates the importance of innovation.

Application to UoE

As shown in the simplified analysis matrix (Table 11), many of the interventions from this case study scored highly and several achieved maximum ratings (highlighted in **bold**).

Table 11: Case Study 8 - Simplified Analysis Matrix

Climate variable	Actions	Implementation phase (max. 8)	Operational phase (max. 5)	Sustainability (max. 9)	Points total (max. 22)
	Re-harling	5	4	**9**	18
	Lime washing	**8**	**5**	-	13
	Restore chimney and flashing	7	**5**	-	12
	Repoint skew copes and other weathering details	7	**5**	-	12
	Double-glazed windows	6	**5**	**9**	20

According to observations, UoE has many Georgian-style buildings similar to the structure in the case study, such as 14–25 Buccleuch Place and the School of Economics (30 Buccleuch Place) which are both category B listed buildings (Figure 7).

Image source: HES, 2016a & UoE, 2017c

Figure 7: Haa of Sand (left); UoE School of Economics (right)

The issues identified or expected to be faced by these UoE buildings - based on the information gathered - are potentially the same as identified in the case study, including damp, water penetration during heavy downpours and inadequate thermal performance. In which case, UoE should consider the repairs and adaptation measures carried out in this case study and should make appropriate enquiries regarding listed building consent, as double-glazed windows are likely inapplicable. Furthermore, the gable-end walls of UoE properties don't have external harling, which might relate to the 19th century fashion change (HES, 2017), and, as a result, the rubble masonry walls are directly exposed to rain and wind with only a thin layer of render protecting the exposed joints. According to HES (2017), modern renders are often cement-based and are not suitable for traditional buildings and can lead to rapid stone decay because of damp trapped inside. Under the current climate change trends, with increasing storms expected, the exposed masonry could suffer greater damages from water penetration leading to disfigured building appearance, and damp penetration resulting in poor thermal performance and increased energy consumption. In that situation, UoE would face both financial and reputational loss.

On the other hand, should UoE apply some of the measures implemented in the case study - especially reharling - there would be further research and educational value beyond financial gains to be explored. As mentioned, the refurbishment team in the case study trialled multiple mortar formulas and came up with a unique solution for the traditional buildings in Shetland that face more brutal weather conditions compared to mainland Scotland. UoE could adopt a similar approach by engaging researchers and students from the departments of Architecture, Chemistry and/or Engineering in collaboration with HES, or other third-party research institutions, to reform the current mainstream 3-coat system and develop new formulas for lime mortar. In such a case, not only will UoE Estates & Buildings be involved but also students and staff, which can offer more experiences to the university as a research institution and an innovative public body, not to mention the potential reputational gains, especially in the case of a novel technique or material reform.

In conclusion, this case study offers valuable information on measures to be taken on listed buildings facing water penetration problems. It can also be applied to the UoE context and serve a greater purpose beyond protecting university properties and also provide opportunities for research, teaching and innovation.

4.1.3 Case Study 14 – Tenement Flats: Wall & Window Upgrades

This case study comes from the Historic Scotland publication series: Refurbishment Case Studies (HES, 2016b) and is comprised of a refurbishment project on traditional buildings (pre-1919) designed to tackle and respond to climate change and covering both mitigation and adaptation measures.

This particular study focuses on mitigation measures, setting out 5 energy efficiency projects demonstrating thermal improvement interventions to traditional tenement buildings – all Category 'B' listed - in Edinburgh. The projects were undertaken with the aim of minimising disruption to the building occupants and in all cases the properties were domestic dwellings. The actions implemented are summarised in Table 12.

Table 12: Case Study 14 - Summary of Actions

Actions	Description
Secondary glazing	Secondary glazing installed in different combinations of frame and glazing type: either timber or aluminium frames with either single or double-glazing installed.
Replacement and upgrading works to external doors	*Proctor Spacetherm* insulation blanket fitted to inside face of door and covered with plywood and sealed. Weather strips and seals also replaced.
Window insulation **Face fixed rigid insulation to wall surface**	Window and wall surface insulation consisted of a combination of *Pavaflex* wood fibreboard and *Kooltherm K12* phenolic insulation board.

Blown insulation into wall cavities	Two varieties of *Warmfill* blown insulation, an expanded polystyrene bead insulation with bonding agent, installed.
Plaster and paint finishes	Traditional plaster finish and clay-based paints – which have excellent moisture absorption properties - applied to wall surfaces.

The actions undertaken yielded considerable thermal improvements, minimised disruption to building occupants and, overall, the study demonstrates that energy use and carbon emissions can be substantially reduced in traditional buildings. The project also won the Carbon Trust Low Carbon Building Award.

The significance of this case study for UoE is that the energy efficiency measures implemented therein are complementary to adaptation actions.

Application to UoE

In terms of location, all 5 of the projects in this case study provide relevant examples that can be readily applied to UoE.

The properties – 4 of them – are all located in central Edinburgh and UoE has either offices or departments in either the same or near-identical buildings.

For example (Figure 8), the UoE Research Support Office is located at 1-7 Roxburgh Place - the location of 3 of the case study properties (top) - and the Music dept. is located at 12 Nicolson Square, which is immediately adjacent to the Marshall Street property (bottom).

Case Study 14 properties	UoE properties
• 2 Roxburgh Street • 6 Roxburgh Street • 22 Drummond Street  *Image source: HES, 2016b*	• Research Support Office • 1-7 Roxburgh Street • Built: 1810  *Image source: HES, 2015a*
• 33 Marshall Street  *Image source: HES, 2016b*	• Music dept. facilities • Alison House, 12 Nicolson Sq. • Built: 1780  *Image source: HES, 2015b*

Figure 8: Similarities Between Case Study 14 Properties and UoE Properties

In terms of the specific actions too, this case study provides a range of relatively low-tech and easily implemented measures that all result in energy efficiency gains, lower energy bills, and contribute towards reducing overall organisational emissions. This is reflected in the high score returned from the multi-criteria analysis, with most actions achieving maximum points (highlighted in **bold**) against most criteria - see Table 13.

Table 13: Case Study 14 - Simplified Analysis Matrix

Climate Variable	Actions	Implementation phase (max. 8)	Operational phase (max. 5)	Sustainability (max. 9)	Points total (max. 22)
	Secondary glazing	**8**	**5**	**9**	**22**
	Replace/upgrade external doors	**8**	**5**	**9**	**22**
	Window insulation	7	**5**	**9**	21
	Wall cavity blown insulation	4	**5**	**9**	18
	Wall face solid insulation	4	**5**	**9**	18

The cost of implementing similar measures is, of course, something that UoE would need to consider, and costs will vary depending on the exact circumstances. The costs presented in this case study relate only to the labour and materials involved in the specific works undertaken and do not include costs for preparatory work, repairs of pre-existing issues and professional fees for arranging Listed Building Consent and architectural services. The average costs were:

- Secondary glazing & window insulation: £1,360/window
- Blown wall insulation: £45/m^2
- Rigid wall insulation: £2,800/wall

While these costs may not seem obviously low, they are indicative of a bespoke solution for a small number of properties and it is expected that UoE would benefit from standardised materials, economies of scale and established relationships with suppliers and contractors.

Of course, it would be wrong to suggest that UoE is doing none of this already. Such measures have been, and continue to be, implemented during refurbishment works of traditional buildings, e.g. the BREEAM 'Outstanding' High School Yards and the in-progress work on the Old Boiler House, which will be the new home for SRS. This case study confirms these good practices while offering scope for further improvement.

The measures outlined in this case study fall more within a climate change mitigation remit, as opposed to adaptation - though the two are not mutually exclusive and do overlap - and this example shows how UoE can protect its traditional buildings and their occupants by undertaking actions that will reduce its overall carbon footprint, improve thermal comfort levels inside buildings during cold spells (which will continue to occur despite general temperature increase), and complement more specific adaptation-oriented actions.

This sub-section has focused on actions that can be applied directly to traditional buildings. The actions presented are comprised entirely of physical interventions designed with either a climate change adaptation or mitigation purpose and are all aimed at enhancing the efficiency and resilience of traditional buildings, as well as improving levels of internal comfort for building users. Existing actions already undertaken by UoE are acknowledged where known. Any physical actions will require appropriate consultation and collaboration with relevant bodies regarding permissions and restrictions concerning traditional buildings. In addition to purely building resilience and efficiency gains, this section has also highlighted additional value for UoE in terms of research, teaching and innovation.

4.2 Non-traditional Buildings & Landscaping

4.2.1 Case Study 11 - Supporting the Implementation of Climate Adaptation Measures

This case study comes from the European Climate Adaptation Platform database (ECAP, 2018a) and describes the ongoing urban climate adaptation project in Bratislava entitled ‘Bratislava is preparing for climate change’. The overall aim of the project is to implement measures to enhance the city’s resilience to the adverse effects of climate change, with a particular focus on management of intense heat and rainfall.

This is a sizeable €3.3m EEA and Norway Grant-funded, multi-stakeholder and multi-faceted project consisting of multiple sub-projects on a range of different scales over several years. Actions taken are focused on light-engineering adaptation measures around blue and green infrastructure on non-traditional buildings and in terms of landscaping. The actions implemented are summarised in Table 14.

Table 14: Case Study 11 - Summary of Actions

Actions	Description
Green roof	1,000m^2 green roof installed on a municipal care home for the elderly, the main function of which is to control water run-off.
Urban rehabilitation **Green spaces** **Sustainable drainage** **Permeable paving** **Underground rain water storage**	A city square of about 1ha replaced by grass, trees and flower beds and including water capture and irrigation systems. 1,000m2 park area established in an area with no previous green spaces and including sustainable drainage systems and underground rain water storage tanks. New housing developments on old industrial ‘brownfield’ sites incorporating multifunctional green leisure spaces with visible water flows.
Tree planting	Trees planted in the historic centre and main square, to provide shade. Two separate tree-lined avenues realised, providing ‘cool corridors’ in city centre areas.

The project is cited as having helped to reduce damage from flooding and to combat the urban heat island effect in the city. And, while difficult to quantify in monetary terms, the initiative is deemed to be making a positive general contribution to people’s well-being by providing green spaces and shaded areas throughout the city.

The significance of this case study for UoE is that multiple stakeholders are engaged in facilitating adaptation action, and though the actions themselves apply to non-traditional buildings and landscaping, these both play an important role in protecting traditional buildings.

Application to UoE

As is clear from the simplified analysis matrix in Table 15, the majority of these actions scored highly and are therefore considered as potential measures that UoE could implement. Again, it should be noted that UoE has implemented some of these solutions already. For example, there are green roof facilities on the Informatics Forum, ECCI bike shed, as well as student accommodation buildings. Green spaces are ubiquitous across the various campuses, as is permeable paving and tree planting, including recent examples such as work completed at Pollock Halls. In fact, all of the actions below can be seen in UoE's Sustainability Award-winning Easter Bush campus, which showcases rain water harvesting systems, green roofs, permeable paving and sustainable urban drainage systems, among other measures.

Table 15: Case Study 11 - Simplified Analysis Matrix

Climate Variable	Actions	Implementation phase (max. 8)	Operational phase (max. 5)	Sustainability (max. 9)	Points total (max. 22)
	Green roof	4	**5**	**9**	18
	Green spaces, e.g. parks	4	**5**	**9**	18
	Permeable paving	7	**5**	3	15
	Underground rain water harvesting	5	4	3	12
	Tree planting	**8**	**5**	**9**	**22**

It is clear then that UoE is already doing many of the 'right things' and the examples in this case study support that sentiment. There is always, however, room for improvement and new projects currently in the pipeline undoubtedly provide the opportunity for more green and blue infrastructure on new builds or as part of refurbishment programs, e.g. the KB Infrastructure Project [Phase 1] (£13m) and the Edinburgh Futures Institute – Quartermile project (£119m).

Figure 9: Crichton Street from Bristo Square

Image source: UoE, 2018b

Other upcoming flagship projects could be at risk from flooding but could also play a facilitative role in mitigating this risk, e.g. the new Student Centre (£82m) on Crichton Street could be affected by rain water run-off from Bristo Square (Figure 9), which, according to anecdotal evidence, has been observed to overload the existing drain.

The cost of implementing such measures on the scale of this case study is not inconsiderable. However, with UoE committing a projected combined total of £214m for only these 3 projects mentioned above, this should be incorporated from the design stage to minimise costs and disruption. With relatively short implementation periods but long operational lifetimes of circa 20yrs for a green roof, 40yrs (at least) for tree planting programs and potentially longer for rain water retention facilities, the benefits will surely outweigh the costs.

Besides the range of individual solutions, this case study also provides a good example of a complex project involving the cooperation and collaboration of multiple parties, some directly financially involved and some not. There were 9 key stakeholders involved, including the Bratislava City Office, 2 city district councils, a consulting group, a water company, 3 conservation groups and a university, and multi-party steering groups, and the case study notes such complex stakeholder networks as both facilitating and limiting the overall success of the project. Issues that are particularly relevant for UoE include ensuring a harmonised approach with local authority permissions and agendas where larger-scale measures that interact with local infrastructure and services are concerned, and archaeological aspects that need to be accounted for in a historical city setting such as Edinburgh.

This case study reinforces that adaptation action on non-traditional buildings and landscaping are both vital in protecting neighbouring traditional buildings from the adverse impacts of climate change. It also serves as a reminder that UoE is already engaged in good practice whilst highlighting the importance of stakeholders working together to achieve common goals.

4.2.2 Case Study 13 - Implementation of Green Urban Infrastructure Strategy

This case study comes from the European Climate Adaptation Platform database (ECAP, 2018b) and describes the implementation of the city of Victoria-Gasteiz's Green Urban Infrastructure Strategy, which focuses on "greening" the urban area and enhancing urban weather resilience. The strategy contains measures aiming to tackle the emerging problems of flooding and the urban heat island effect under climate projections which indicate that the city will experience significant increases in rainfall and temperature in summer.

The on-going operation was assigned a budget of over €15m to deliver the desired outcome and its many sub-projects engaged different parties, including private shareholders, students, and over 5,000 local residents. The actions implemented are summarised in Table 16.

Table 16: Case Study 13 - Summary of Actions

Actions	Description
Transform vacant plots into green spaces	Launched a 2 million Euro "Green Ring" project to naturalize green spaces and vacant plots
Increase biomass by planting more trees and shrubs	Refurbished the Gasteiz Avenue by restoring river corridor, planting trees along the road and creating a car-free eco-street
Enhance habitat functions of green spaces	Initiated a green spaces protection agenda starting in Lakuabizkarra neighbourhood and covered over 50 spaces
Promote ecological agriculture	
Apply living walls	Installed a green wall on the Congress Palace Europa
Hold awareness campaigns	Hold tree-planting days that involved more than 2500 citizens and delivered speeches and awareness campaigns across local schools and engaged with over 3000 students

Although difficult to assess in monetary terms, it is evident that the implementation of the strategy has contributed to urban biodiversity, rehabilitation, habitat preservation, a reduced urban heat island effect and lower energy consumption.

The significance of this case study for UoE is that it demonstrates that green spaces play a vital role in climate adaptation, and, although it is more about landscaping, it can contribute to the protection of traditional buildings and the well-being of people. Furthermore, the involvement of citizens and stakeholders is essential and UoE should consider engaging with people at multiple levels when implementing similar projects.

Application to UoE

As shown in the analysis matrix (Table 17), the actions scored highly, indicating that these are effective measures available for deployment by the university. However, it must be acknowledged that UoE has already applied many of these solutions to various locations across its estate, as well as a few areas currently in the planning, e.g. the Old College Quad was rehabilitated and spread with lawn and the new Greenwood facility, currently in the design phase, will have a living wall.

Table 17: Case Study 13 - Simplified Analysis Matrix

Climate variable	Actions	Implementation phase (max. 8)	Operational phase (max. 5)	Sustainability (max. 9)	Points total (max. 22)
	Increase green space	5	**5**	**9**	19
	Increase biomass	**8**	**5**	**9**	**22**
	Preserve habitats	**8**	**5**	-	13
	Living wall	6	**5**	**9**	20
	Awareness campaign	**8**	**5**	**9**	**22**

On another note, the preservation of existing green spaces should be considered under circumstances where UoE is expanding campuses and building more facilities, as it is equally important to maintain existing green areas as it is to add new ones. Such green spaces are habitats to various local species and also provide educational value. They also serve students, staff and nearby residents as places to relax. Thus, the often-neglected conservation measures should be highlighted and valued.

This case study also serves as a fine example of good communication among city council, stakeholders and citizens. UoE should engage with the City of Edinburgh Council regarding landscaping and green space management and design to incorporate campuses into the city of Edinburgh and enhance connectivity and biodiversity as a comprehensive joined-up system. As will be discussed further in the communication section below, it would be beneficial to involve students, staff and citizens in these activities so that the concepts of climate change adaptation and mitigation can take root among the wider public and to better assist the development of UoE and the city.

This sub-section has focused on actions that can be applied to non-traditional buildings and landscaping of the surrounding areas. The actions are comprised entirely of physical interventions designed with a climate change adaptation purpose and are presented here because of the important role they play in protecting more vulnerable traditional buildings to climatic changes. Existing actions already undertaken by UoE are acknowledged where known and recommendations for improvement provided where appropriate. The measures discussed have an additional, more human element too, as green spaces and green infrastructure can help to provide respite from increasingly high temperatures as well as foster a general ‘feel good’ factor. This section also highlights some of the issues related to large-scale, multi-stakeholder initiatives and serves as a reminder of good collaborative practices and the value therein.

4.3 Stakeholder Engagement & Communications

The focus of the analysis in this section is less about the implementation of physical adaptation measures and discusses two examples focused largely on stakeholder engagement and communication strategies that demonstrate the value and significance of community-oriented approaches that may provide useful insight for UoE.

4.3.1 Case Study 9 - Building Community Resilience to Flooding

Case Study 9 (Climate Just, 2014) describes a successful example of local residents mobilising to tackle a serious flooding problem. The village of Hampshire had been severely impacted by flooding on several occasions, motivating the city council and residents to create a community flooding-response plan. The overall strategy was to mobilise the entire community to be active participants in a range of actions, in association with the local emergency services. The actions are summarised in Table 18.

Table 18: Case Study 9 - Summary of Actions

Actions	Description
Overall strategy	Involve the local community to build momentum among residents so that they may collaborate towards achieving a common goal: flooding mitigation actions in this case.
Resident engagement	Local residents were engaged to help identify the most vulnerable areas to flooding, e.g. entries to schools and shops, which helped demarcate flood water trails (Figure 10).
Management	A Flood Action Group was established, comprised of local residents and emergency services expertise to provide guidance and decision-making.
Expertise	Local expertise was enlisted to map and identify risk and to formulate a water flow management strategy.
Education	Hampshire emergency services published books about the measures undertaken and distributed them to local schools (Figure 10).

Image source: ClimateJust, 2014

Figure 10: Sandbags and Flooding in Hambledon (left); Flood Education Book for Local Schools (right)

These measures proved highly effective. After only 2 years' implementation, heavy rain saw 55% of expected annual rainfall in only 7 weeks. However, due to the actions implemented, the cost of the clean-up amounted to only £3,600: a huge improvement on the £309,000 incurred 20 years earlier for a similar-scaled event.

This shows that the residents developed the ability to respond to flooding without having to rely on the emergency services and demonstrates the value and significance of a community-led approach. The significance of this case study for UoE is that it provides an example of how to engage and manage stakeholders into successfully deploying a risk action plan.

Application to UoE

The key message from this case study for UoE is that, similarly, developing awareness, capacity and competence among its students and staff would be an effective way towards tackling climate change related issues and would make for a more independent and resilient estate.

While flooding has not been, and is unlikely to be, as grave a concern for UoE as in this case study, as has been discussed above, it is an important issue: the King's Buildings campus and George Square areas have both recently experienced flooding. There may however, be limited public awareness of the flood risk that UoE may face in the future and the risk that this poses to traditional buildings and UoE should consider raising awareness of these risks, especially risks for traditional buildings. This could be done by delivering information to a wider audience in a more creative way, e.g. UoE could enlist the help of art and design students to work on information brochures and campaigns about climate change risk and adaptation at UoE, or perhaps support students to devise a related program or performance as part of the Edinburgh International Festival.

UoE might also consider more in-depth involvement of staff, students and other key internal stakeholders in identifying vulnerable traditional buildings and surrounding areas in accordance with their own experiences. UoE may also wish to consider developing student capacity in terms of monitoring and measuring the effects of measures applied to traditional buildings. Utilising the student body and everyday building users as 'expertise' in this way could facilitate a more nuanced and fit-for-purpose set of solutions and could yield results like those in this case study that are effective in increasing awareness and reducing physical damages and repair/maintenance costs. Any such measures implemented would, of course, require guidance and input from professional bodies, as well as relevant internal departments.

This case study provides a reminder of the importance of effective management, guidance and support processes necessary for meaningful stakeholder relations and engagement. Costs for this are difficult to quantify, but staff time will a key factor. UoE already has plans for a flood management team (SRS, 2017), and will need to consider how best to allocate resources and staff efficiently. Making traditional buildings 'climate ready' is something that was not prioritised previously and UoE will need to ensure sufficient budget and resource towards this end.

4.3.2 Case Study 10 - Climate-Proofing Social Housing Landscapes

Case Study 10 (ECAP, 2018c), again, gives a good example of how to engage with a range of stakeholders. Organised by Groundwork London (an environmental charity) and two community councils, the project implemented social housing landscaping measures in three different districts aimed at dealing with winter flooding and summer heatwaves.

Involving a range of stakeholders including residents, local unemployed people, building companies, green infrastructure specialists, sustainability expertise from the local university, local government, other relevant associations and NGOs, this project demonstrates a successful approach and set of outcomes for a multi-stakeholder endeavour. The various actions are summarised in Table 19. Figure 11 shows some of the green infrastructure measures implemented.

Table 19: Case Study 10 - Summary of Actions

Actions	Description
Residents engagement	Engaged in design process, applied for the 'Sustainability Champions' of community, received free training about how to install, maintain and manage their green space effectively, attended the maintenance handover meetings with the contractors.
Unemployment	Groundwork London designed accredited apprenticeship programmes for local long-term unemployed people, taught them landscaping skill and provided work opportunities for people who successfully passed the qualification.
University	University of East London got involved in the project by technically monitoring and verifying the effectiveness of measures, ongoing and after the project's close.
Professionals and ground maintenance contractors	A series of training modules has been developed and delivered for senior managers, housing professionals and grounds maintenance contractors through the whole process, engaged in 46 people.

Image source: ECAP, 2018c

Figure 11: Green Infrastructure in the Community

The outcomes from this project include a more engaged community and reduced long-term maintenance costs, both of which combined create a profound and lasting positive social impact.

The significance of this case for UoE is that it demonstrates some of the bigger-picture benefits of such a comprehensive community engagement strategy. It also highlights the potential for green infrastructure projects to generate outcomes that are socially, economically and environmentally beneficial.

Application to UoE

Effective stakeholder engagement and communications are important contributors to not only the success of any adaptation measures, but also to the enhancement of the UoE brand. The draft adaptation strategy considers internal collaboration, e.g. student scholarships and cooperation with relevant departments and initiatives such as ECCI and Climate-KIC innovation projects. UoE is also engaged with a wide range of local, external stakeholders, e.g. it plays an active role in City of Edinburgh Council initiatives such as the Resilient Edinburgh-Climate Change Adaptation Framework, Edinburgh Adapts - Climate Change Adaptation Action Plan & Vision and participates in the Edinburgh Living Landscapes program. For traditional buildings, Historic Environment Scotland is already a key partner, though there is scope for a more comprehensive and wide-ranging approach to safeguarding UoE traditional buildings. Continued collaboration along similar lines will bring reputational benefits for UoE.

Potential applications for UoE from this case include engaging students and staff in landscape design, and also for adaptation solutions for traditional buildings, and providing any training required. Students and staff could in turn look after green infrastructure around traditional buildings. To encourage participation, participants would be ‘rewarded’ with an enhanced sense of ownership of the UoE estate while making a positive contribution towards preservation of university operations, the environment and natural resources.

This sub-section has focused on the importance of stakeholder engagement and communication strategies within the context of climate change adaptation programs. While not all of the actions listed are readily applicable to the UoE context, e.g. UoE is highly unlikely to experience life-threatening flooded rivers running through its campuses, it is rather the overarching strategies and means of delivery that are of relevance for UoE. Similarly, the measures discussed are not specifically related to traditional buildings, but their relevance is universal and readily applicability to any climate change adaptation or mitigation project.

Examples of existing actions already undertaken by UoE are again acknowledged where known and recommendations for improvement provided where appropriate. This section also highlights some scope for UoE to consider more creative approaches involving other areas of UoE activity and thus the potential to make an even greater social contribution.

The various actions and initiatives discussed in this case study analysis section represent genuine potential 'win wins' for UoE, in that they address broader climate change concerns that are perfectly aligned with wider UoE ambitions and commitments while also highlighted opportunities for additional value creation.

A more detailed and comprehensive list of specific actions is provided in Appendix D, including a cost-benefit analysis of (i) implementing the actions outlined in the 'best practice' case studies presented above, as well as (ii) a wider range of potential actions taken from the full set of case studies that were analysed for this study.

5 Conclusion

The aim of this study was to identify 'best practice' climate change adaptation solutions to enhance the resilience of UoE traditional buildings. In order to do this, impacts from past weather-related events on UoE were outlined, providing an 'adaptation baseline', and future climate change projections were given to indicate the scale and severity of the problem going forward. A definition for traditional buildings and an assessment of the value and importance of traditional buildings for UoE were then given. This was followed by a comprehensive multi-criteria analysis of 17 climate change adaptation case studies, which was further streamlined to 7 case studies, which were discussed in the main body of the report in terms of their application to UoE.

The overall conclusions that this study makes are that in order to make its traditional buildings 'climate ready' and to minimise disruption to core activities and operations UoE should adopt a comprehensive approach to adaptation that involves actions applied to traditional buildings themselves, as well as non-traditional buildings, landscaping measures, stakeholder engagement and communications. Such a comprehensive approach should involve exploration for creative collaborations and maximising the value for UoE by recognising and utilising the resource that it has at its disposal: its large staff and student body and wide-ranging research, teaching and innovation expertise. This fits with the whole-institution approach outlined in the Climate Strategy 2016-2026 and will build on existing good practice.

5.1 Recommendations for UoE

This study acknowledges that UoE is already doing the 'right things' and presents evidence to support that sentiment. This study also provides scope for further improvement and suggestions for more creative approaches to embed climate change adaptation and mitigation behaviours into the daily goings on of UoE. More specifically, this study offers the following recommendations:

- Given the importance of traditional buildings to UoE core operations and brand image, UoE should consider a more proactive approach to making its traditional buildings more resilient to a changing climate: an approach that involves proper assessment, implementation and ongoing monitoring and maintenance.
- Non-traditional buildings, landscaping, stakeholder engagement and communications are important in protecting traditional buildings from climate change. UoE should continue to implement and apply, where possible, all the good measures that it already has implemented as well as the measures highlighted in the case studies presented herein with regard to these key areas.

5.2 Limitations of this Study

There were several issues deemed to have had a limiting effect on this study. The first was the difficulty experienced in accessing data. Secondary data is widely available for climate change adaptation, though adaptation case studies related to traditional buildings were found not to be in abundance. Access to data was also hampered by difficulties in engaging key personnel within UoE internal department, e.g. Estates and Buildings. The group made repeated attempts to request data and/or face-to-face meetings, but this proved very difficult. Some data was obtained – and referenced in the report – though this information came indirectly via our client, Dr Elizabeth Vander Meer. Secondary data is of course available, and was referenced extensively, but the group felt that primary data from an internal UoE department would have lent credibility and greater relevance to this study's findings. Academic pensions strike action was also deemed to have affected access to the client to some degree.

There are also likely to be limitations in this study's findings, due in part to the issues mentioned immediately above and in some measure to the fact that UoE is already engaged in a range of adaptation endeavours.

5.3 Suggestions for Further Research/Work

UoE would benefit from an appraisal of the real value of its traditional buildings as well as a more detailed, professional climate change adaptation risk assessment of all its traditional buildings. This would be a not inconsiderable piece of work and would require close collaboration with relevant UoE internal departments so that data access does not become an issue. This would go some way to putting a figure on the cost of adaptation for UoE traditional buildings.

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Appendix A – Case Study List

Case study 1-19 th Century House [4]

Challenges	Solutions	Significance	Cost and Benefit	Photo
• Fail to regulate indoor temperature. • Lack of shading from the sun • Poor ventilation	• Solar shading • Ventilation: The system is automatically controlled to maximize the cooling potential from outside air. The ventilation system provides maximum ventilation whenever indoor temperatures are above 24°C and above the outside temperature.	• Reduce the time period that in uncomfortable temperature • No additional energy consumption.	• No specific cost data	
				Applications to UoE
				• Paterson's Land

[4] Hacker, JN., Belcher, SE. & Connell, RK. (2005) Beating the Heat: keeping UK buildings cool in a warming climate. UKCIP Briefing Report. UKCIP, Oxford.

Case study 2-Rainwater harvesting [5]

Challenges	Solutions	Significance	Cost and Benefit	Photo
• Flooding risk • Water shortage	• Install five 1,000 liter rainwater harvesting tanks in the unused space in the roof • Collecting rainwater by the process of rainwater harvesting • The collected water used in flush toilets	• Reduces flood hazards. • Environmental friendly. • Sufficient water management.	• Tanks: $600–$2,200 depending upon size and style • Connect tanks to plumbing: $300-$1,000 or more	 **Applications to UoE** • Grant Institutes • King's Building Campus

[5] Connelly, A. (2011) Adapting office buildings for climate change – literature review. EcoCities project, University of Manchester, Manchester, UK.

Case study 3-Bewdley School Science Block [6]

Challenges	Solutions	Significance	Cost and Benefit	Photo
• Flooding	• Two opposite direction roof planes for two distinct flow paths for roof run-off. • The water collection and conveyance by a series of channels, rills, and grass swales, and stored in open basins, raingarden, rill and pond help to slow down the run-off • The new plaza helps to store the water	• Educational value to students • Enhancing the landscape • Preventing the flooding	• No specific cost data	 **Applications to UoE** • George Square

[6] https://www.robertbrayassociates.co.uk/projects/bewdley-school/

Case study 4 -Islington Town Hall [7]

Challenges	Solutions	Significance	Cost and Benefit	Photo
• Public space need hard surfacing. • Hard surfacing causes high speed of rainwater runoff and flood risk. • Having potential challenge to keep the landscape and historic feature.	• Using gravel or other permeable material that design the hard surfacing to be permeable. • Building area filters that go through the permeable paving, underground chamber and finally the drains.	• Both maintained hard surfacing to keep functioning and made adaptation to climate change. • The process helps to clean the water and reduce the runoff rate especially heavy rainfall that help reduce the pressure to drainage system. • Not only no impact on historic features of buildings, but also make this place more attractive.	• No specific cost data • Permeable pavers per square foot range from \$4.00-\$6.00. (vary with the availability of using material)	 **Applications to UoE** • George Square

[7] https://www.islington.gov.uk/~/media/sharepoint-lists/public-records/environmentalprotection/information/guidance/20112012/20120303conservationsustainabilitynote

Case study 5-Park in Madrid, Storm water retention (2014) [8]

Challenges	Solutions	Significance	Cost and Benefit	Photo
• Poor water infiltration, intense water runoff and erosion in the event of heavy rains; • Flooding • High volume of rainwater entering the waste water management system carried great burden on system capacity and caused problems of water overflow	• Replacing the eroded and compacted soil with permeable soil; • Reconstructed sealed surface and pavement with new permeable materials in order to enhance drainage capacity and water penetration • Installed underground rainwater harvesting system under pavement and permeable surface • Planted more trees and spread the lawn	• Erosion and flash flooding during heavy rain events have been prevented • creating a sustainable water cycle system and unloaded pressure from wastewater management system • Increased moisture in the soil that also helps to ameliorate the Urban Heat Island effect in and around the park	• Cost: The construction cost was €343,600 (approximately € 34/m2) and covered by the municipality of Madrid • Benefit: No further maintenance costs compared to traditional landscaping solutions and brought multiple benefits that are beyond monetary assessment	 **Applications to UoE** • George Square • Pollock Halls

[8] http://climate-adapt.eea.europa.eu/metadata/case-studies/the-refurbishment-of-gomeznarro-park-in-madrid-focused-on-storm-water-retention

Case study 6-Urban storm water management in Augustenborg, Malmö (2014) [9]

Challenges	Solutions	Significance	Cost and Benefit	Photo
• Lower level garages and basements were damaged due to surface water/flooding • Sidewalks and roads were blocked during event of heavy rain • Waste water treatment system overloaded with rainwater causing untreated sewage entering watercourse • Flooding	• Built a new storm water management system consisted of 6km of canals/water channels and 10 retention ponds • Installed 30 green roofs on nearby buildings including 2100 m^2 were provided on residential houses • Built a 9500 m^2 roof garden named the Botanical Roof Garden on an old industrial building	• Occurrence of flooding in the area has been lowered to minimum since the storm water management system was installed • The system protected the nearby urban area from an "once in 50 years" strom • 90% of water runoff was collected by the storm water management system • The total annual runoff volume is reduced by about 20% compared to the conventional system	• Cost: € 0.72 million for building the Botanical Roof Garden • Benefits: Increased biodiversity by 50%. Reduced carbon emissions and waste generation by 20%	 **Applications to UoE** • King's Buildings Campus

[9] http://climate-adapt.eea.europa.eu/metadata/case-studies/urban-storm-water-management-in-augustenborg-malmo

Case study 7-Old Building Refurbishment [10]

Issues	Solutions	Significance	Cost	Photo
• Chimney Stack: The majority of the lime mortar joints had disappeared because of long periods of wind driven rain saturation and dampness, which leaded to serious water leakage inside the building • Roof: Slates were at end of life, with corroded fastenings and rotten sarking boards, draining the water from roof into the cellars • Wall: suffering from dampness • Rainwater goods: the rainwater goods were in damage and caused water leakage problem	Roof: -Installed new sarking boards, covered with a vapour-open roofing membrane paper for watertight during extreme weather while maintain the breathability of building. -Replaced, redressed and reinstated 50% of the roof slates, and supplemented timbers where suffered from roof leak -Installed replacement lead flashing along the roof ridge to prevent the water penetration Redesigned and replaced the rainwater goods with new cast iron rhones and downpipes	Maintain a suitable balance between historical appearance and improved equipment Combination of traditional techniques with improved modern materials Refurbished an old, dilapidated building to a warm, dry one which is suitable for living, and the changes have been working effectively for 10 years	No specific cost data	 Application for UoE • Buccleuch Place (EH8 9LN)

[10] https://www.historicenvironment.scot/archives-and-research/publications/publication/?publicationid=8cc7810d-f82b-4f8a-a1bd-a6ad00a1608f

Case study 8- Shetland, Hot-mixed mortar re-harling and adapting a gable end wall [11]

Issues	Solutions	Significance	Cost	Photo
• Water ingression at several locations. • The roughcast of the south gable wall was cracked and got bossed in at several places; • The lintels above the windows were badly damaged leaving opens for water penetration; • Chimney in poor condition with degraded cope stone; • Improperly installed flashing and lead abutment.	• Re-harled gable using a one-coat, thin harl and the mix of traditional Shetland harling. • Replaced chimney cope with improved weathering and drip details; • Lime washing for the re-harled gable wall; • Repointed skew copes with hot-mixed lime mortar paired with lime washing; • Replace windows	• No sign of dampness on the interior finishes; • Thermal performance increase for the rooms with new double-glazed windows; • Although moisture monitoring show only modest improvements in moisture levels the gable wall with new harling and lime wash is coping adequately with the driving rain.	• Average cost of harling and lime washing is £10/m^2 • Benefit: Protect external walls especially gables from water ingression and damp penetration, and enhance thermal performance	 **Application for UoE** • Side walls of 14–25 Buccleuch Place (EH8 9LN) • Side walls of School of Economics (30 Buccleuch Place)

[11] https://www.historicenvironment.scot/archives-and-research/publications/publication/?publicationid=158a5511-b667-4e03-8b84-a716009fb9cb

Case study 9-Building Community Resilience to Flooding (Hampshire) [12]

Issues	Solutions	Significance	Cost	Photo
• Heavy rainfall – 55% of expected annual rainfall in only 7 weeks - leading to severe flooding • Previous similar incident caused extensive damage and a 6-week clean-up/repair program cost £309,000 • Emergency services on-site for 6 weeks	• Community-led approach • Local residents' Action Group established • Information made available Roles and responsibilities appropriately assigned	• Highly effective, collaborative approach lessened the impact • Costs significantly reduced Greater community cohesion and awareness	• Cost of action negligible due to community-led, collaborative approach • Clean-up/repair costs reduced from £309,000 to only £3,600 • Emergency services only nominally impacted	 **Application for UoE** • General application

[12] http://www.climatejust.org.uk/case-studies/building-community-resilience-flooding-hampshire

Case study 10-Climate-Proofing Social Housing Landscapes – Groundwork London and Hammersmith & Fulham Council (2016) [13]

Issues	Solutions	Significance	Cost	Photo
• Surface water flooding due to lack of green spaces across 3 social housing estates in London • Enhanced 'urban heat island' effect due to lack of green spaces and resulting reduced evaporative cooling effect	• Light-engineering adaptation measures around blue and green infrastructure, including: ○ Green roofs ○ Rain gardens ○ Food beds ○ Tree planting ○ Permeable paving • Community engagement and training	• Increased urban resilience to climate change • Community engagement key to success – residents can be experts on their local environments • 3,158m^2 of impermeable surface diverted to green spaces • 325 trees planted • 432m^2 green roofs installed	• €526,000, co-funded by local and wider authority initiatives • 100% of rainfall diverted from storm drains • 89% of rain absorbed by green roofs • 1, 286,815 litres annual rainfall diverted by adaptation measures • £4.39 SROI (Social Return on Investment) for every £1 spent	 **Application for UoE** • King's Building's campus

[13] http://climate-adapt.eea.europa.eu/metadata/case-studies/climate-proofing-social-housing-landscapes-2013-groundwork-london-and-hammersmith-fulham-council

Case study 11-EEA grants supporting the city of Bratislava to implement climate adaptation measures (2016) [14]

Challenges	Solutions	Significance	Cost and Benefit	Photo
• Rise in average temperature • More heat-waves -> long periods of drought, due to longer dry periods • Extreme rainfall -> increased flooding	Light-engineering adaptation measures around blue and green infrastructure, including: • Green roofs • Permeable paving • Tree planting • Rain water harvesting • Sustainable drainage	• Increased urban resilience to climate change • 1 ha of impermeable pavement replaced by grass areas, trees and flower beds • $1000m^2$ green roof, to divert excess rainwater • Tree-lined 'cool corridors' provide shade and evaporative cooling	• €3.3m, EEA Grants and local authority funding • Expected savings on reduced damage from flooding • Mitigation of adverse impacts to health from heat-waves	 **Applications to UoE** • King's Building's campus

[14] http://climate-adapt.eea.europa.eu/metadata/case-studies/eea-grants-supporting-the-city-of-bratislava-to-implement-climate-adaptation-measures

Case study 12-Environment-friendly urban street design for decentralized ecological rainwater management in Ober-Grafendorf, Lower Austria (2017) [15]

Issues	Solutions	Significance	Cost and Benefit	Photo
More frequent and intense heavy precipitation during drought period Excessive surface water over sealed areas -> flooding Overloading of the sewer and wastewater treatment system Cost of irrigating and maintaining the urban greenery rises as summer becomes hotter and dryer	Build an eco-street of 100 meters length and 11 meters width Develop a specifically soil substrates with high water permeability and high storage capacities Carefully select suitable plant species which are easy to maintain and adjusted to the local weather Plant with shrubs and soil-covering species to prevent drivers and walkers from damaging the system	Water the plant while integrate water into ground water system Each cubic metre of substrate can store up to 500 litres of water With life cycle of 50 years, assure flood protection up to heavy precipitation events with a 50 year return interval	Cooling capacity equals to a 100-years-old beech tree on a hot summer day, is able to reduce the local temperature by up to 5°C during heat periods Substrate/one cubic metre = 100 Euros Cultivation cost = two Euros / m for seeding Several thousand Euros / m for planting large woody perennial plants	 Application for UoE Edinburgh BioQuarter

[15] http://climate-adapt.eea.europa.eu/metadata/case-studies/environment-friendly-urban-street-design-for-decentralized-ecological-rainwater-management-in-ober-grafendorf-lower-austria

Case study 13-Implementation of the Victoria-Gasteiz Green Urban Infrastructure Strategy (2018) [16]

Challenges	Solutions	Significance	Cost and Benefit	Photo
• Based on climate expectation, there will be 10-30% less rainfall in spring by 2100 • Event of extreme downpours is expected to increase by 30% • Temperatures during summer and winter are expected to increase up to 3 oC. • Conclusion: higher risk of flooding and heatwave in the near future	• Transform vacant plots into green spaces • Increase biomass by planting more trees and shrubs • Enhance habitat functions of green spaces • Promote ecological agriculture • Apply living walls • Hold awareness campaigns	• Increased biodiversity in urban area and improved conservation of local species and water management • Green walls improved thermal performance and acoustic insulation of host buildings • Encouraged public participation and involvement, offered educational services	• Costs: Budget for green facade – 10 million Euros; Green ring – 2 million Euros (4 year's implementation); Neighborhoods adaptation – 415,000 Euros. • Benefits: Reduce the heat island effect, reduce energy consumption in buildings and reduce temperature of surroundings	 **Applications to UoE** • Edinburgh Future Institute - Quartermile

[16] http://climate-adapt.eea.europa.eu/metadata/case-studies/implementation-of-the-vitoria-gasteiz-green-urban-infrastructure-strategy

Case study 14-HES Refurbishment Case Study 1 – Five Tenement Flats, Edinburgh: Wall & Window Upgrades [17]

Challenges	Solutions	Significance	Cost and Benefit	Photo
• Poor overall energy efficiency • Poor thermal performance • Poor acoustic performance	• Secondary glazing • Replaced and upgraded external doors • Fitted insulation to window reveals	• Considerable thermal improvements - U-value reduced ubiquitously • Demonstrates that energy use and carbon emissions can be substantially reduced in traditional buildings	• Secondary glazing: £1,360/window • Blown insulation: £45/m^2 • Rigid wall insulation: £2,800/wall	
				Applications to UoE
				• King's Building's campus

[17] https://www.historicenvironment.scot/archives-and-research/publications/publication/?publicationId=cfd327b0-395b-4c4f-9999-a59300f138bd

Case study 15-HES Refurbishment Case Study 4 – Sword Street, Glasgow: Internal Wall Insulation to Six Tenement Flats [18]

Challenges	Solutions	Significance	Cost and Benefit	Photo
• Poor overall energy efficiency • Poor thermal performance • Concerns over moisture release	• Range of insulation types blown into wall cavities • Range of solid insulation types fixed to solid walls with plaster coat	• Considerable thermal improvements - U-value reduced ubiquitously • No significant rise in average humidity levels resulting from interventions • Demonstrates that improved thermal performance can be achieved using materials sympathetic to existing building fabric	U-value improvement of 34-81%	 **Applications to UoE** • Paterson's Land, Holyrood Road

[18] https://www.historicenvironment.scot/archives-and-research/publications/publication/?publicationid=651e6f16-087f-408b-ab3d-a59300fd971a

Case study 16-Newtongrange [19]

Issues	Solutions	Significance	Cost	Photo
• Poor thermal performance • Concerns over moisture release	• Secondary glazing • Insulation blown into wall cavities • Replace degraded mineral wool with 'breathable' sheep's wool insulation	• Minimal disruption - residents remained on-site • completed within 3 weeks • Considerable thermal improvements - U-value reduced • Relatively low cost • No damage to existing building fabric	• Secondary glazing: £1,360/window • Blown insulation: £45/m^2 • Sheep's wool insulation: ~£230 • Reduction in energy bills • Improved acoustic performance	 **Application for UoE** • 1-10 Hope Park Square

[19] https://www.historicenvironment.scot/archives-and-research/publications/publication/?publicationId=db047b98-e3b3-4af2-96f1-a59300f48ac8

Appendix B – Definition of Criteria in Multi-criteria Analysis

Criteria	Definition	Standard
Climate variable	The climate issues covered in the case study	3 different icons representing rainfall, overheating and thermal performance
Disruption	Disruption to the normal operation of the building Disruption to access of the facility	***Low***: no disruption or minimal disruption to normal operation or access (3 points) ***Medium***: require partial termination of operation or limited access (2 points) ***High***: total shutdown of the facility and no access (1 point)
Time-period	The construction time	***Low***: 0-2 months (3 points) ***Medium***: 2-4 months (2 points) ***High***: >4 months (1 point)
In-house **External contractor**	Construction require in-house team or external contractor	***In-house***: covered by university construction team (2 points) ***External contractor***: need to hire professional construction team (1 point)
Ongoing maintenance	Maintenance required to take during the operation and maintenance period	***Low***: no maintenance requirement or minimum (3 points) ***Medium***: require extra attention (2 points) ***High***: regular maintenance and even require external assistance (1 point)
In-house **External contractor**	Whether require in-house or external contractor for maintenance	***In-house***: covered by university maintenance team (2 points) ***External contractor***: need to hire professional maintenance team (1 point)
Energy efficiency	Use less energy or produce more energy	Yes (3 points) / No (0 point)
Emission reduction	Reduce emission because of the measure taken	Yes (3 points) / No (0 point)
Cost saving	Cost reduction because of the measure taken	Yes (3 points) / No (0 point)

Appendix C – Case Study Analysis Matrix

Category	Case study	Climate variable	Action	Implementation phases								Operational phase					Sustainability potential			Points	
				Disruption			Time period			In-house (I) /external contractor (E)		Ongoing maintenance			In-house (I) /external contractor (E)		Energy efficiency gains	Emission reduction	Cost saving	Action	Case study
				L (3)	M (2)	H (1)	L (3)	M (2)	H (1)	I (2)	E (1)	L (3)	M (2)	H (1)	I (2)	E (1)	(3)	(3)	(3)		
Traditional	Case study 1		Solar shading	✓			✓				✓	✓			✓		✓	✓	✓	21	60
			Natural ventilation	✓			✓				✓	✓			✓		✓	✓	✓	21	
			Mechanical ventilation		✓		✓				✓		✓			✓	✓	✓	✓	18	
	Case study 2		Roof rainwater harvesting	✓			✓				✓		✓		✓				✓	14	14

Traditional	Case study 7		Built new chimney stack with reclaimed brick	✓			✓				✓		✓		✓					11	56
			Installed new roof sarking board & roofing paper		✓		✓			✓		✓			✓					12	
			Redressed& reinstated roof slates		✓		✓			✓		✓			✓					12	
			Installed roof replacement lead flashing	✓			✓			✓		✓			✓					13	
			Redesign-ed & replaced rainwater goods			✓	✓				✓		✓			✓				8	
	Case study 8	 	Reharling			✓	✓				✓	✓			✓		✓	✓	✓	19	76
			Restore chimney	✓			✓				✓	✓			✓					12	
			Lime washing	✓			✓			✓		✓			✓					13	
			Repoint skew copes	✓			✓				✓	✓			✓					12	
			Double-glazed window		✓		✓				✓	✓			✓		✓	✓	✓	20	

Traditional	Case study 14		Secondary glazing	✓			✓			✓		✓			✓		✓	✓	✓	22	101
			Replace/upgrade external doors	✓			✓			✓		✓			✓		✓	✓	✓	22	
			Window insulation		✓		✓			✓		✓			✓		✓	✓	✓	21	
			Wall cavity blown insulation			✓		✓			✓	✓			✓		✓	✓	✓	18	
			Wall face solid insulation			✓		✓			✓	✓			✓		✓	✓	✓	18	
	Case study 15		Wall cavity blown insulation			✓		✓			✓	✓			✓		✓	✓	✓	18	36
			Wall face solid insulation			✓		✓			✓	✓			✓		✓	✓	✓	18	
	Case study 16		Secondary glazing	✓			✓			✓		✓			✓		✓	✓	✓	22	62
			Wall cavity blown insulation			✓		✓			✓	✓			✓		✓	✓	✓	18	
			Sheep's wool insulation	✓			✓			✓		✓			✓		✓	✓	✓	22	

Landscape	Case study 3		Roof planes			✓		✓			✓	✓				✓				8	26
			A serious of channels, rills, and grass swales		✓			✓			✓	✓				✓				9	
			New plaza		✓			✓			✓	✓				✓				9	
	Case study 5		Permeable soil	✓				✓		✓		✓			✓					12	57
			Permeable surface and pavement	✓				✓			✓	✓			✓					11	
			Underground rainwater harvesting system		✓			✓			✓		✓		✓				✓	12	
			Plant trees	✓			✓			✓		✓			✓		✓	✓	✓	22	

Non-traditional &landscape	Case study 4		Permeable paving	✓			✓				✓	✓			✓		✓	✓	✓	21	21
	Case study 6		Storm water management system		✓				✓		✓		✓		✓		✓	✓	✓	17	37
			Green roof and roof garden		✓		✓				✓	✓			✓		✓	✓	✓	20	
	Case study 11		Green roof		✓				✓		✓	✓			✓		✓	✓	✓	18	85
			Green spaces, e.g parks		✓				✓		✓	✓			✓		✓	✓	✓	18	
			Permeable paving	✓			✓				✓	✓			✓				✓	15	
			Tree planting	✓			✓			✓		✓			✓		✓	✓	✓	22	
			Underground rain water harvesting		✓			✓			✓		✓		✓				✓	12	

Non-traditional &landscape	Case study 12		Build an eco-street	✓			✓			✓		✓			✓		✓	✓		19	59
			Develop specifically soil substrates	✓			✓				✓	✓			✓		✓			15	
			Carefully select suitable plant species	✓			✓				✓	✓			✓					12	
			Plant with shrubs and soil-covering species	✓			✓			✓		✓			✓					13	
	Case study 13		Increase green space		✓			✓			✓	✓			✓		✓	✓	✓	19	96
			Increase biomass	✓			✓			✓		✓			✓		✓	✓	✓	22	
			Preserve habitats	✓			✓			✓		✓			✓					13	
			Living wall		✓		✓				✓	✓			✓		✓	✓	✓	20	
			Awareness campaign	✓			✓			✓		✓			✓		✓	✓	✓	22	

Appendix D – Cost-benefit Analysis of Adaptation Action/Inaction

Traditional Buildings

Issue	Impact	Building Feature	Potential Action	Inaction		Action	
				Cost	Benefit	Cost	Benefit
Heavy rain	*Water penetration through chimneys and flues*	*Traditional building with chimneys built within the gable wall*	*Install lead step flashing for chimneys*	*Water run-off around chimney stack and penetrates through the chimney cope*	*No capital outlay and no need for listed building consent*	*£300-1000* [20]	*Increase weather resilience and protect building fabric from water penetration through chimneys*
			Repoint degraded mortar joints around chimney stacks			*£500-1000* [21]	
			Obstruct unused flues using vented chimney cowls, chimney balloons or hearth boards	*Damp enter flues and worsen stonework decay and reduce thermal performance during winters*		*£50-200* [22]	*Protect the gable walls from damp and increase ventilation during summers*

[20] https://www.jjroofingsupplies.co.uk/blog/lead-flashing-answers/
[21] https://www.homebuilding.co.uk/restoring-chimneys/
[22] https://docherty-group.com/chimney-balloons/

Heavy rain	*Wind-driven rain reaching under roof coverings*	*Traditional buildings with slates or pantiles coverings*	*Install waterproof roofing underlays /breathable roofing paper*	*Roof water leakage during stormy weathers and damage roof timbers*	*No capital outlay and no need for listed building consent*	*£10-50/m^2 for the underlay* [23]	*Reduce water ingression and protect building fabric*
			Fix zinc or lead ridge rolls onto the verge (the roof junction with the gable wall)	*Wind-driven rain penetration around the junction and damages interiors*		*£30-50/verge of material* [24]	
Heavy rain	*Wind-driven rain entering through windows and doors*	*Traditional buildings without weather-stripping windows and doors*	*Cut a narrow rebate into the edge of the stile, fit in a strip of brushes, vinyl, rubber or polyurethane foam, and install thresholds*	*Physical and financial damage to properties in the building*	*No capital outlay and no need for listed building consent*	*£5-20* [25] *varies with material used*	*Prevent the building from water penetration and save the cost of fixing or replacing otherwise damaged properties*

[23] https://www.jjroofingsupplies.co.uk/flat-roofing/torch-on-felt/
[24] https://www.jjroofingsupplies.co.uk/zinc-copper-aluminium/
[25] https://www.par-direct.co.uk/

<table>
<tr>
<td rowspan="3">Heavy rain</td>
<td rowspan="3">High volume of water flow on the roof</td>
<td rowspan="3">Traditional buildings</td>
<td>Retain or install additional roof water disposal details (e.g. water-gates, storm rolls and skew copes, etc.)</td>
<td>Inadequate rainwater disposal ability leads to water ingression</td>
<td rowspan="3">No capital outlay and no need for listed building consent</td>
<td rowspan="2">Depends on specifications</td>
<td>Effective water run-off and prevent water penetration</td>
</tr>
<tr>
<td>Maintain and upgrade existing rainwater drainage systems (e.g. downpipes, parapet gutters and rhones, etc.)</td>
<td>Water overflow pipelines and damage the adjacent masonry with extended saturation</td>
<td>Provide sufficient draining capacity in the event of intense rainfall and reduce the chance of blockage</td>
</tr>
<tr>
<td>Install rainwater harvesting system</td>
<td>Insufficient water management and utilisation of rainwater</td>
<td>£700-2500 [26] varies with system size and feature;

Need to consult local planning authority</td>
<td>Use rainwater o increase internal water supply and reduce water bills from mains water consumption</td>
</tr>
</table>

[26] https://www.rainwaterharvesting.co.uk/

Heavy rain	*Damage to external walls (especially the gable walls) due to driving rain*	*Traditional buildings*	*Lime harling*	*Water penetration and build-up of moisture within the walls, causing damage to interiors, reducing thermal performance and can lead to structural deformation*	*No capital outlay and no need for listed building consent*	*Starting from £10/m^2 depending on the material* [27]	*Protection against driving rain and lower chance of cracking compared to cement, the use of breathable mortar helps reduce moisture in the wall*
			Lime washing				*Additional waterproofing coat that consolidate the harling and increase masonry durability under worsening weather conditions*
Flooding / Surface Water	*Flooding of ground-floor or basements- level*	*Traditional buildings with basements or offices under the ground floor*	*Install flood barriers at openings to lower ground floors*	*Physical and financial damage to the properties on ground floor and basement level, damage from hasty clearing up, sewage contamination and dampness on underground- level walls and rooms*	*No capital outlay*	*Depends on specifications*	*Protect properties, create a comfortable environment for students, lecturers and staff in underground classrooms and offices, prevent disruption to teaching and researching activities*
			Reroute existing pipes & services below ground				
			Reopen of previously blocked air vents				
			Apply internal lime plaster onto the existing masonry with breathable coating				

[27] http://www.limestuff.co.uk/breathable-paints-limewash/limewash-pure-white/

Overheating /hotter summers	*Increased thermal stress on building fabric and high temperature within the building because of warmth accumulation*	*Traditional buildings with overheating problems*	*Install traditional blinds to increase shading and reduce heat*	*Building fabric could be damaged due to hot weather and affect appearance. Occupants could experience health issues due to high temperature and teaching / studying activities would be interrupted due to such incidents*	*No capital outlay and no need for listed building consent*	*£20-50 [28] varies with material used*	*Traditional buildings could be better protected during extreme hot summer periods and students and staff can enjoy the facilities the traditional buildings have to offer in a more comfortable environment*
			Use flexible traditional materials to repair (e.g. lime mortars)			*Starting from £10/m^2 depending on the material [29]*	
			Install modern ventilation system			*Depends on specifications*	

[28] https://www.selectblinds.com/traditional-window-coverings.html
[29] http://www.limestuff.co.uk/breathable-paints-limewash/limewash-pure-white/

Strong wind	*Wind lift of roof coverings or unstable masonry*	*Traditional buildings with slates or pantiles coverings and unsecured chimneys*	*Cheek nailing*	*Roof coverings can be blown apart in the event of strong wind*	*No capital outlay*	*Depends on specifications*	*Secure the roof and protect the structural integrity of the building against wind lift*
			Lime mortar torching or bedding				
			Repair and secure chimneys using matching stone and good detailing	*Masonry may be blown from the roof and cause safety issue*			*Secure chimneys, protect appearance of the building and prevent the occurrence of safety incidents*

Non-traditional Buildings

Issue	Impact	Building Feature	Potential Action	Inaction		Action	
				Cost	Benefit	Cost	Benefit
Heavy rain	*Roof water ingression*	*New buildings or buildings under construction planning*	*Green roof*	*Water collects on roof during intense rainfall and penetrates building fabric*	*No capital outlay and no concern for the roof weight bearing capacity*	*Around £100/m^2 depending on specifications* [30]	*Absorb rainwater, limit water run-off and reduce roof water ingression and can increase bio-diversity*
Overheating /hotter summers	*High temperature within the building due to accumulation of warmth*	*All buildings without adequate ventilation or cooling systems*	*Living wall*	*Occupants can feel uncomfortable or even fall ill under high temperature and it would affect or interrupt operation of the university and incur both financial and reputational loss*	*No capital outlay*	*Around £100/m^2 depending on specifications* [31]	*Reduce the overall temperature in the building during hotter summers without consuming extra energy*
			White roof			*£2.5-5/m^2* [32]	
			Window blinds and external shading (e.g. wooden louvres)			*Depends on specifications*	
			Upgrade or install new ventilation systems				*Cool the building and stabilize the overall temperature at a comfortable level and*

30 https://www.renewableenergyhub.co.uk/green-roof-information/how-much-do-green-roofs-cost.html
31 http://architek.com/products/vertical-gardens
32 https://www.epa.gov/heat-islands/using-cool-roofs-reduce-heat-islands

							guarantee the well-being of its occupants

Landscape

Issue	Impact	Building Feature	Potential Action	Inaction		Action	
				Cost	Benefit	Cost	Benefit
Flooding/ surface water	*Flooded surface areas*	*Landscape and areas adjacent to all buildings*	*Maintain and upgrade existing drainage or install additional drainage systems*	*Temporary loss of walkways, sewage contamination, limited or blocked access to university facilities and financial damages due to water ingression at lower ground levels*	*No capital outlay*	*Depends on specifications*	*Reduce flooding risk, provide the staff and students a safer environment for teaching, researching and learning, protect university properties and help generate a more appealing campus*
			Rain garden				
			Green infrastructures (e.g. street trees, permeable pavement, and sustainable urban drainage systems, etc.)				

Climate Ready Traditional Buildings at the University of Edinburgh

Carbon & Environmental Consulting Project

28 March 2018

Authors: 6967340, B120405, B115684, B118765

THE UNIVERSITY of EDINBURGH

Social Responsibility and Sustainability