SAHC

Moisture Problems in Irish Tower Houses:
Application to Barryscourt Castle

Conor Paul Meehan

Portugal | 2011

ADVANCED MASTERS IN STRUCTURAL ANALYSIS
OF MONUMENTS AND HISTORICAL CONSTRUCTIONS

Master's Thesis

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Education and Culture

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This Masters Course has been funded with support from the European Commission. This publication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Portugal I 2011

DECLARATION

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Year: 2011

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

I hereby declare that the MSc Consortium responsible for the Advanced Masters in Structural Analysis of Monuments and Historical Constructions is allowed to store and make available electronically the present MSc Dissertation.

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Date: 25/July/2011

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“I am not young enough to know everything” - Oscar Wilde

- *Dedicated to my long suffering parents who wait in cross-fingered hope that someday I’ll become a success and pay them back.*

ACKNOWLEDGEMENTS

I would like to thank my overseeing supervisor Prof. Luís Ramos for his guidance, helpful suggestions, encouragement and *excel* wizardry throughout the course of this thesis. I would also like to thank Prof. Sandra Silva for her help during the course of the thesis, and for her site accompaniment during the thermography testing section of this thesis study.

Many thanks are owed to the many lecturers at UPC in Barcelona, for sharing their expertise and knowledge throughout the course of the SAHC coursework classes. A special thanks to Prof. Pere Roca for his assistance throughout the SAHC year and for encouraging me to pursue a thesis topic of my own choice. Further thanks to Prof. Miloš Drdácký and Prof. Marius Vendrell for sharing their thoughts and suggestions regarding the intervention proposals for moisture infiltration. I am also very grateful to the European Consortium for awarding me a scholarship to partake in this Masters course and giving me the opportunity to follow my passion for the conservation of building heritage. Additional thanks to Ms. Dora Coelho for her Trojan work and organisational assistance throughout the year.

I warmly acknowledge the involvement, support and assistance of all members of the Office of Public Works in Ireland, to all the helpful staff at the various OPW sites which were visited during this study. Specials thanks to Aighleann O'Shaughnessy for taking her time out of her busy schedule to answer my many questions regarding the castle, scheduling appointments and sharing essential information. I also want to thank Flora O' Mahony for her assistance with drawings and figures.

Many thanks to the helpful guides at Barryscourt castle for allowing me access to the castle between tours and for sharing valuable knowledge regarding the castles history and restoration. A special word of thanks to Sir Robert of Barryscourt, who was always helpful and obliging during the course of this thesis study, and for sharing his knowledge but more importantly, his tea and cakes, during the long days spent at the castle.

My work is dwarfed by the pain staking toil which was endured by my family in dealing with me throughout my existence. I appreciate all their support and encouragement – I hope to use my newly acquired knowledge to restore the old stables at the back of our home for my parents - a modest old-folks home as repayment. Unfortunately our coursework did not involve biological restoration, so my father will still need to have his hip replaced.

Finally, my heartfelt thanks to all the friends and comrades I have met throughout this year and before – their banter, loyalty and friendship is the finest reward of all.

Conor Meehan

ABSTRACT

Moisture infiltration is one of the main causes of structural decay in buildings in northern Europe. Ireland's precipitous climate leads to Irish buildings been frequently exposed to rain and wind and this barrage plays a large part in the destruction and decay of many of Ireland historic buildings and monuments. One type of historical building in particular that suffers due to the effects of continued water infiltration is the Irish tower-house.

Dotted all over the Irish countryside, the Irish tower-house is the most common type of castle in Ireland. These medieval fortified dwellings became the construction of choice for powerful families during the late medieval period in Ireland. Several hundred tower-houses remain today, with most in a serious state of dilapidation or disrepair. The small portion of tower-houses which have been fortunate enough to be chosen for restoration, continue to suffer due to water infiltration causing large scale damage throughout the castles including biological growth, structural element decay and material deterioration, – all of which can lead to eventual structural decay and irreversible damage.

This thesis involved a detailed damage assessment and analysis of the current condition at Barryscourt tower-house in County Cork, Ireland. Barryscourt castle is experiencing extensive problems due to water infiltration. The study involved several visual inspections, non-destructive testing (NDT), monitoring tests and absorption testing of the component materials to isolate the main causes of moisture infiltration throughout the building.

It was found that the buildings main moisture problems originate from poor roof drainage and leaking, rising dampness and most concerning, through the porous lime mortared, limestone masonry. This thesis outlines several intervention methods to prevent the infiltration of moisture throughout the building including the reintroduction of an external protective lime-mortar render, a layer which would have originally covered the masonry walls to protect from the weather.

Due to the similarities between all Irish tower-houses and the typicality of their construction, the methods and solutions outlined in this study can be applied to tower houses all over the country, helping to conserve an integral aspect of Irish building heritage.

RESUMO

A infiltração de humidades é uma das principais causas de deterioração estrutural em edifícios no norte da Europa. A significativa ocorrência de precipitação na Irlanda leva a que os edifícios estejam frequentemente expostos à chuva e ao vento, tornando-se no principal fator na destruição e deterioração de muitos dos edifícios históricos e monumentos. Neste contexto, as torres fortificadas são o tipo de construção histórica que mais sofre devido aos efeitos da infiltração de água.

Espalhadas por todo o interior da Irlanda, as torres-casa (ou castelos) são o tipo mais comum de construção fortificada no país. Estas construções medievais tornaram-se a primeira escolha das famílias poderosas para habitação permanente. Várias centenas de torres perduraram até hoje, mas a maioria encontra-se em estado grave de deterioração ou em ruína. As torres que tiveram intervenções de reabilitação no passado continuam expostas à infiltração de água, causando danos de larga escala em toda a construção, tais como a atividade biológica, a deterioração dos materiais e a degradação dos elementos estruturais.

A presente tese envolveu uma avaliação detalhada do estado de conservação atual do castelo Barryscourt, em County Cork, Irlanda. Presentemente, o castelo de Barryscourt tem problemas devido à extensa infiltração de água. Para determinar as principais causas de infiltração de humidade, o estudo envolveu várias inspeções visuais, ensaios não-destrutivos (NDT), monitorização dos parâmetros ambientais, no interior e exterior do castelo, e ensaios de absorção de água nos materiais utilizados na construção.

No castelo de Barryscourt verificou-se que os principais problemas são relacionados (a) com as infiltrações de água pelas coberturas, devido à sua reduzida impermeabilidade, (b) com as humidades ascensionais e (c) devido à absorção de água das paredes exteriores devido à grande porosidade das argamassas de cal e à inexistência de revestimento (reboco) exterior.

Para minimizar os efeitos negativos da infiltração de humidades, a tese aponta vários métodos de intervenção, que incluem a reintrodução de um reboco, à base de cal, para melhor proteger a construção das intempéries, técnica essa que se pensa ter sido já utilizada no passado para minimizar os efeitos negativos da humidade na construção.

Devido às semelhanças existentes entre os castelos irlandeses, os métodos e as soluções apresentadas neste estudo podem ser aplicadas às construções fortificadas em todo o país, contribuindo, assim, para melhor conservar o património edificado da Irlanda.

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1 INTRODUCTION

Ireland is one of the wettest countries in Europe with convincing precipitation records as proof (European Climate Atlas Project, 2004). One of the leading causes of structural decay of Irish buildings is precipitation and the infiltration of water into the structures due to the constant barrage of rain and the elements. This infiltration leads to mould growth, corrosion and material decay, all of which can lead to structural deterioration.

Water infiltration is of particular concern with historic projects because the interior of the structure often has significant details including ornamental plaster, frescoes, woodwork or other finishes that are irreplaceable or extremely expensive to restore. Due to the nature of their construction and composite materials, almost all historical buildings exhibit extensive damage due to water infiltration and this on-going battle with the elements calls for further study into the identification of sources, the different mechanisms of infiltration and the comprehensive intervention eliminating the threat.

The Irish tower house was a popular structure built by those in power during the 14th century through to the 16th century. They are dotted all over the Irish landscape and indicate a period of turmoil and unrest in Ireland through their defensive design, features and strategic locations; however, these fortresses also worked as homes for governing figures and their families. Sadly, throughout the ages, these buildings have been abandoned and many lie in decay due to neglect. Those which have been lucky enough to be chosen for restoration projects stand in proud testament to the tradition of the structure and its stance in Irish history. These castles are renowned landmarks/popular attractions and valuable cultural assets to natives and tourists alike.

Unfortunately, even when these tower houses are fully structurally restored they are susceptible to water infiltration through the porous exteriors and act like sponges to the precipitous surrounding environment. Moisture ingress has become an accepted phenomenon in tower houses and is seen as an unstoppable part of the construction design. Feeble previous attempts have been made to slow moisture ingression or improve interior conditions by heating or other temporary sealing methods and to this day, even the most recently restored tower-houses show large scale deterioration and decay due to the continued presence of moisture and other damaging factors which are by products of this presence.

This study is motivated by the understanding that the continued damage of these buildings is leading to their already rapid decline. This study aims at tackling this problem, isolating the causes and mechanisms for this infiltration in tower houses with the intention of developing comprehensive solutions to intervene in this damaging process. These Irish tower houses are similar in design and construction, so by focusing on one in particular, in this case, Barryscourt castle, the building can be studied in detail along with its construction typology and its response to the wet climate. Barryscourt castle underwent a full structural restoration in 1996 yet to this day it still experiences and suffers from moisture ingression.

Once an understanding of the structures behaviour in wet conditions has been gained, interventions can be developed to combat this threat and allow the same procedures to be applied to tower houses all over the country. It can also be applied to other castles of a similar nature also which are found in both Britain and Ireland, which also suffer due to the wet climate.

This study begins by exploring the construction history and pattern of the Irish tower house, the evolution of their design for its intended purpose of security and shelter, and its significance in Ireland during this turbulent period in history. Relevant studies and previous interventions will be reviewed and evaluated for effectiveness considering the most up to date research, ideas and materials.

Structured site investigations and damage assessment surveys will be conducted to assess the state of damage in the castle and isolate regions that warrant significant attention. Non-destructive thermographic testing methods will be used to identify where moisture is infiltrating and will help to study how the walls behave following wet conditions. Water absorption tests will be conducted on the component materials of the castle to determine those more responsible for the moisture ingress, and thus, focusing attention on the most important aspects. The building will also be monitored using up to date data loggers which will record the everyday conditions and fluctuations in the climatic environment both internally and externally.

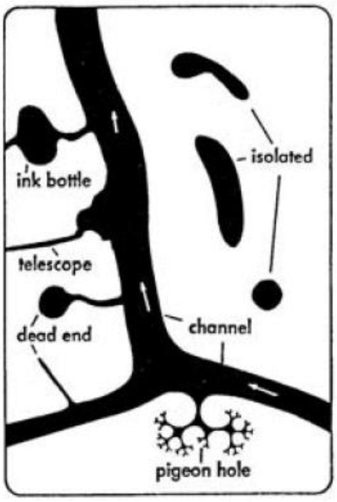
This comprehensive study will give an added insight into these largely misunderstood structures and by isolating the causes of the water infiltration, along with previous studies and intervention projects will permit the author to construct an intervention procedure to protect the structure from the elements and secure its 600 year legacy into the distant future.

2 LITERATURE REVIEW

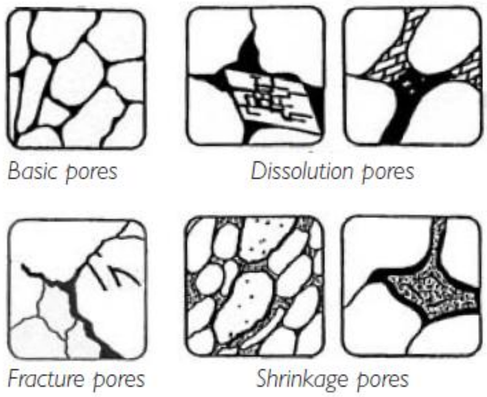
This study involves a range of issues and aspects surrounding the conservation of historical buildings and cultural heritage. The thesis revolves around the problems experienced by a historical type of medieval construction, the typical Irish castle, or tower-house. The origins and development of these historic structures is explored and discussed in the next chapter (Chapter 3, *The Irish Tower House*), as a background for the thesis study. The main topic of this study is regarding moisture infiltration and the damaging effects that this ingress causes to the building, its interior environment and its constituent materials. It was therefore necessary to research this topic and the negative effect that moisture has on building materials, and in particular, masonry. Barryscourt castle, the subject of this thesis study, is constructed from limestone masonry block units and a traditional lime based mortar.

2.1 Moisture as a Damaging Substance in Historical Buildings and Materials

Water has a major role in the deterioration of masonry materials and as a result, a negative and often devastating influence on buildings. Historic buildings are even more susceptible to moisture damage, due to the centuries of weathering and erosion, materials surfaces become degraded and the once smooth resilient outer surfaces gradually wear down increasing pore exposure and further voids for moisture to lodge inside. In order to understand the phenomena for water transport through materials is important to examine the subject of porosity. Porosity is a measure of the void spaces in a material and is expressed by as a fraction of the volume of voids over the total volume of the material in question. These pores can have a whole range of sizes and arrangements depending on the studied material. An example of the different models and types can be found in the following Figure 1.



(a)



(b)

Figure 1: (a) Different pore models (b) Different pore types (Fitzner, 1993)

Just as is the case in Barryscourt castle, as can be seen the following chapters, solid media transports the water via a network of interconnecting channels which facilitate its transportation. Stone material and mortars can absorb water from the surrounding environment in vapour form (depending on the relative humidity) or in liquid form (from direct contact with water such as rain, condensation and rising damp) (Torraca, 1988). The general characteristics of limestone's porosity can be briefly summarised in the following table, Table 1.

Table 1: Porosity and pore type of limestone (Borrelli, 1999)

Rock Type	Genesis	Geological Formation		% Porosity	Predominant Pore Type
		Pressure	Temperature	(Average Value)	
Limestone	Sedimentary	Low	Low	15 – 20	Micro/Macro

Borrelli's section of the ICCROM manual (Borrelli, 1999) explains porosity in detail how moisture can infiltrate through media via different mechanisms in both liquid and vapour form as follows:

By liquid form:

- Capillary action – when a dry porous material comes in contact with water, its smaller pores fill with liquid which in turn eventually form over the entrance to a larger pore eventually causing it also to fill. This chain process is known as capillary action;
- Diffusion – water passes from one area to another within the material due to passage from a water filled area to an area free from water;
- Osmosis – when soluble salts are contained in the water, dissociation into ions attracts and repels water molecules through the media via electrical force.

By Vapour form:

- Vapour Diffusion – similar to liquid diffusion, the moisture is transported from pores of a high moisture vapour to areas of lower vapour moisture levels;
- Hygroscopic absorption – (hygroscopic means to absorb or attract moisture from the air). This phenomenon can occur also at temperatures above dew point (dew point – temperature at which water vapour in the air is saturated). This process is increased in the presence of soluble salts which in turn are hygroscopic and absorb water under average conditions of relative humidity;
- Condensation – when the temperature of the media is less than dew point, the water vapour condenses within the pores. This can even happen before dew point in small pores.

The moisture at Barryscourt is moving through the building through a combination of these mechanisms, introducing further problems along the way. Apart from being a damaging agent by its own behavioural properties, the presence of moisture is a prerequisite for most degradation processes and acts as an agent which introduces further agents of destruction with regards to masonry and building materials. The interaction between water and a porous medium is one of the main causes of stone deterioration and can lead to weathering from different mechanisms such as the following (Meng, 1993):

- Chemical reaction – pollutants soluble in water can cause chemical damage to the material;
- Physical mechanism – induced stresses such as those experienced during wet/dry and freeze/thaw cycles. The expansion and contraction of the moisture under these conditions induces cyclic stresses in the material, which over time, cause significant fatigue which can eventually lead to material disintegration and detachment;
- By transporting dissolved salts through the material – the dissolution and recrystallization processes within the internal pores can cause serious damage and material disintegration;
- By providing an essential life giving substrate for biological growth and activity.

Because of the effects generated by these mechanisms, the water permeability of a masonry material is related to its durability.

Furthermore, more recent studies have explored the effect of moisture and porosity on the compressive strength and modulus of elasticity of masonry units (Witzany et al., 2003). As part of this research, core boreholes from historical sandstone and arenaceous marl masonry were taken and subjected them to water saturation. The samples were then tested and measured for their strength and elasticity in the laboratory.

After testing, the results were analysed and presented interesting results showing that sandstones with a greater proportion of pores sized ϕ 10-100 μm react more intensely, showing a more progressive drop in the compressive strength f_b and the modulus of elasticity E with the growing pore saturation degree as compared to the sandstone with a greater proportion of pores sized ϕ 0.1-1 μm. Further tests revealed a similar drop in the respective parameters was also observed in arenaceous marl. Some of the test results from these experiments can be viewed in the following figures, Figure 2 and Figure 3.

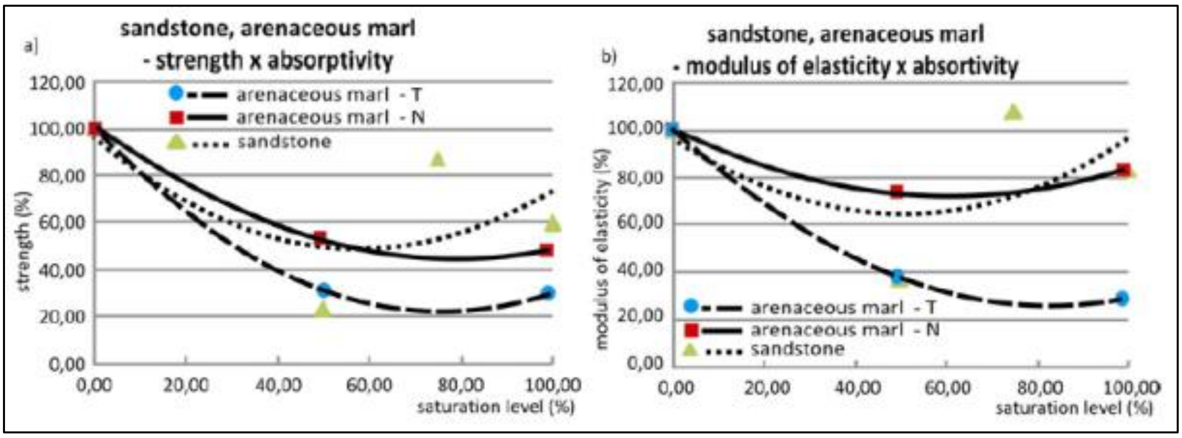


Figure 2: Graphs showing the relationship of compressive strength f_b and modulus of elasticity E of sandstone and arenaceous marl w.r.t. saturation degree determined from core boreholes with dimensions of ø 35 mm & length 70 mm of brick, sandstone, and arenaceous marl (Witzany et al., 2003).

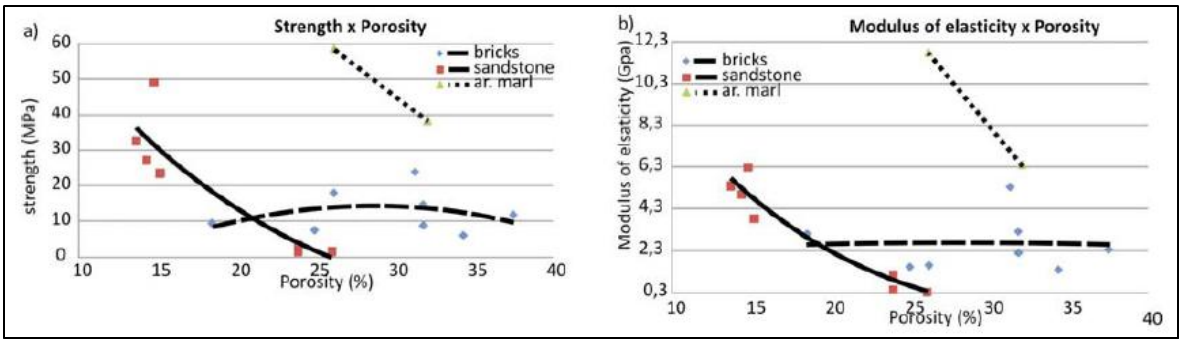


Figure 3: Graphs showing the relationship of modulus of elasticity in compression E and compressive strength f_b w.r.t. porosity (Witzany et al., 2003).

Additionally, the study investigated the effect of moisture on the load bearing capacity and rigidity of masonry pillars. The results also showed how there was a relative drop in the load carrying capacity and an increased deformation as a result of high moisture presence content by weight in the pillars.

This study gives further proof of the negative effects that moisture presence causes a hosting material, and also how the greater proportion of pores has a greater adverse effect on the compressive strength and elasticity of the material.

2.2 Biodegradation of Historical Structures due to Moisture Presence

The abundance of moisture in the porous media and the ideal conditions, provoke the growth or organic vegetation. The presence of this bioactivity has many knock on effects on the masonry and the structure itself. Climatic conditions such as winds help to transport vegetation seeds, or fungal spores against the building surface where they lodge and feed from the nutrients of the surrounding materials and obtain water from the internal moisture, which explains the small to large plants which commonly occupy voids and crevices on the façades of historical buildings (Yaldiz, 2010).

(Yaldiz, 2010), continues by showing how additional smaller organisms can gain a hold of moisture laden masonry also including harmful lichens and mosses. These organisms can survive in the most extreme of conditions and typically begin to appear where there is a healthy supply of moisture. Increased humidity allows the lichens and mosses to spread over building façades, and can begin to increase the speed of deterioration on monumental buildings. Areas of historic buildings which do not receive much attention such as poor rainwater drainage systems and elevated joint and surface voids or gaps run the risk of allowing the development of mosses and vegetation of various magnitudes.

The effects of biodegradation are quite serious, especially if left for extended periods of time. In a recent study into the microbial deterioration of building materials and constructions, the author (Wasserbauer, 2003) describes the effects that microbes have on historic buildings. Bio-corrosion of building stone is a synergic process that corrodes masonry under the presence of moisture. Microbes that grow on the stone surface can produce mineral and organic acids that dissolve calcium silicates and aluminates in stone material. Consequently, following this dissolution, damaging water-soluble salts are generated which penetrate deep inside the masonry units and mortar joints.

The list of damages caused by the presence of microbes includes:

- Strength loss of woodwork constructions;
- Hydrophobic finishes experience functional loss;
- Mould infection of whitewashes;
- Exposure to microbes can induce illness.

The microbes also influence:

- The corrosion of many different types of stone including sandstone and limestone;
- The corrosion of plasters;
- The formation of crusts which in turn can increase the pulverising effects of weathering on building materials;
- Mortar disintegration in joints, especially when the masonry moisture presence increases;

- The corrosion of metal reinforcements or metallic features.

Microbial degradation of building fabric is heavily influenced by the mineralogical composition of the media themselves (such as constituent carbonates, mica and clay minerals). However, this is not the only influencing characteristic; the biological degradation is also influenced by petrophysical parameters of the material (i.e. the inner surface size and the porosity), the orientation of the building (shaded walls or walls in direct sunlight) and the local climatic conditions (Wasserbauer, 2003).

Following on from this, Wasserbauer (2003) describes biocorrosion of moist building stone. The gradual stone degradation is actually generated by a range of microorganism communities. These organisms depend on the securement of nutrients generally obtained at the stone surface. The origin of these nutrients can be from sourced via the soil moisture capillary elevation throughout the masonry, the transport of various nutrients by rainwater runoff or seepage or by the adsorption of dust and hydrocarbons from pollutants on the stone surface.

2.3 Salt Damage to Historic Buildings

As briefly mentioned earlier, salt damage is a huge issue with historical buildings. These salts can originate from a range of sources. One of the main sources is from water-soluble salts which are wicked from surrounding soils up through masonry via capillary forces. This is particularly evident in buildings, such as Barryscourt, that do not possess horizontal water-proofing insulation. In this type of unprotected masonry foundation, the walls soak up the water containing the dissolved salts. The transporting moisture eventually evaporates on or just below the surface of the wall, leaving salt residue and crystal deposits behind (efflorescence). These remaining salt crystals gradually contribute to the dilapidation of the building during wetting and drying, consequently affecting the buildings aesthetic value and vulnerability to further damages from salts or other weathering agents (see Figure 4). Masonry salts can also originate from reaction of acid forming gases in the atmosphere with the basic constituent materials of the building. As described in the outlining of the dangers of bioactivity, some salts can be generated as a by-product of living organisms and microorganisms (Fiala, 2005). A more recent study done by Zezza states that salt decay processes, when "*linked to marine aerosol, sea floods, rising damp and the saline content of the rainfall, are amongst the most recurrent and severe causes of damage to European cultural heritage* (Zezza, *2006*).*"*

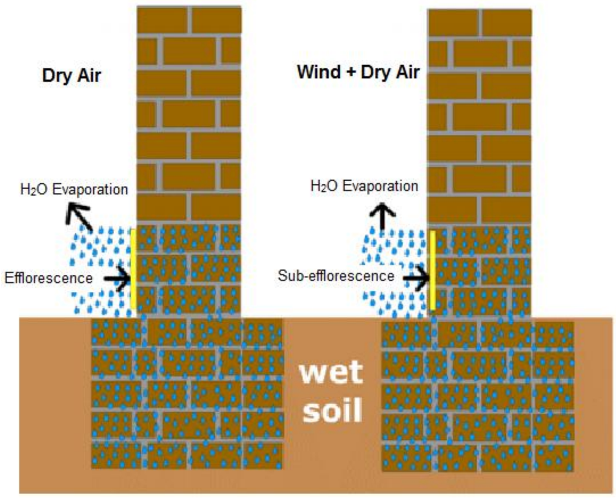


Figure 4: Salt presence arising from rising damp and associated damaging efflorescence (Collepardi et al, 1994)

2.4 Testing Methods and Intervention Approaches

In order to identify the effects of the moisture infiltration, visual inspections and non-destructive testing methods will be employed to further the understanding of the buildings behaviour when subjected to precipitous conditions. When participating in any project concerning environmental or climatic conditions and their effect on a structure, certain tests and analyses should be carried out to further the knowledge and understanding of the problem at hand and to guide to the design of comprehensive and compatible interventions for the prevention of moisture infiltration. Some common interventions are shown in the following

Table 2: Summary of common intervention methods of moisture problems in historic buildings

Problem	Possible intervention methods
Damage due to rising damp	Installation of mechanical barrier; Introduction of physico-chemical barrier by chemical injections; Introduction of ventilation channels
Damage due to salt presence	Firstly, eliminate source of transporting moisture (see rising damp solutions) – Sacrificial rendering; Poulticing (introduction of absorbent covering); Chemical Washing
Falling damp (Moisture originating from upper sections of building)	Inspection and repair of roof, joint seals, guttering and rainwater evacuation devices
Penetrating damp (through outer walls and mortar due to continued precipitation)	Repointing; Sealing of voids/cracks; Improvement of mortar quality; Rendering

All of the methods summarised in the previous table, Table 2, should be preceded by a comprehensive study of the material, the damaging agents (testing of salts if necessary) and an analysis of all technologies, both traditional and recent, in order to derive the best intervention procedure. This procedure should comply with restoration practice and conservation guidelines in order to maintain the integrity of the monument.

Traditional intervention techniques were analysed, in order to gain an understanding of the historic methods used to control moisture infiltration in heritage buildings before moving on to modern procedures. Problems and failures such as incompatibility with modern methods/materials along with new conservation guidelines are causing many modern damp proofing measures to be abandoned in favour of the historical practices and technologies which had evolved over centuries. It also became obvious that in many cases, these traditional materials fare much better and prove more suitable for restoration and construction than modern materials.

Interesting descriptions of historic technologies for the moisture proofing of buildings are outlined in a recent of the heritage site of the Cistercian monastery in Plasy of the Czech Republic (Traditional historical technologies for moisture proofing of buildings, unknown author (n.d.)). In this work, various construction methods are discussed for the prevention of moisture ingress in the Plasy cloister. This building was built on non-load-bearing swampy land as a masterpiece of traditional skills and craftsmanship. Oak driven piles provide the foundation for the structure in the waterlogged ground. The structure supports are permanently irrigated using clean water which ensures the preservation of the wooden bearing foundation support elements, therefore it is of the utmost importance. Waterproofing for the structures walls consisted of thin slate plates which were intended to prevent the capillary rise and upon which a course of loose laid sandstone blocks which in turn underlay the masonry foundations. Consequential lack of knowledge and the loss of skills, allowed the water to creep 0.3 metres above the original line of sandstone blocks. Soluble salts were transported by the water into the lower regions of the structure causing large scale damage (see Figure 5).

Figure 5: Damage to walls of Palsy Cloister, Czech Republic, due to rising damp and salt presence - *Traditional historical technologies for moisture proofing of buildings, (n.d.)*

The process of restoration first involved the careful study of the ingenious original arrangement and the integral influencing elements of the waterproofing system, which included a water feeding system, a water discharge system, a visual control system and an extensive array of ventilation systems. It was necessary to introduce precautions against the threat of rising damp in the building due to the constant flooding of the wooden piles at Plasy. This was done by using an intricate series of air vents used to aerate and subsequently dry the eternal walls. A crawl way ventilation channel was built around the external structure and connected to the external environment of the interior cloister through a series of air ducts which opened at the window sills. A similar ventilation channel system is found in the baroque style *Sala Terrena* in the Wallenstein Garden in Prague (see Figure 6). The ventilation of the whole building was either from the outside of the building, or alternatively, the inside of the building, depending on the temperature differential (Traditional historical technologies for moisture proofing of buildings, unknown author (n.d.)).

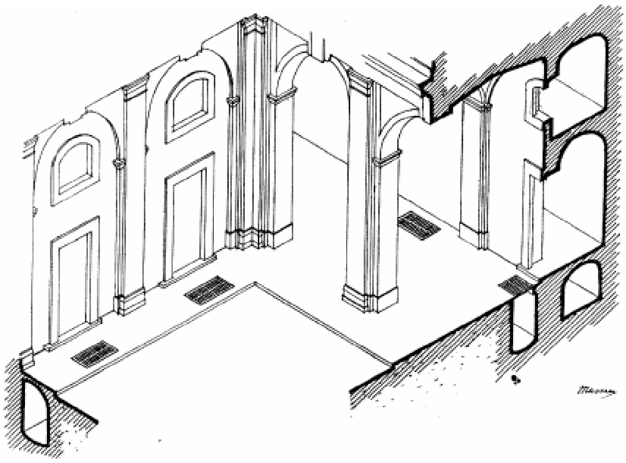
(a)  (b) 

Figure 6: (a) Cross section illustration showing typical ventilation channel around foundation found in Baroque buildings (b) Corresponding ventilation vents around channel – (*Traditional historical technologies for moisture proofing of buildings, (n.d.)*)

This study clearly illustrated the remarkable ingenuity and level of sophistication of historic constructions, even regarding moisture control. The reconstruction of historical drainage systems must be respected for the art that it is, systems that if maintained or reintroduced can work just as effectively as most modern intervention techniques. The study also explored further methods of ventilation systems for the drying of internal walls.

Interestingly, there is very little research done on the drainage and water proofing with regards rising damp for Irish tower houses. Archaeological studies have shown layers of seashells as a means of impeding moisture transportation yet systematic construction procedures need to be explored more extensively. Historical technologies such as the one applied at Palsy could be applied to help prevent the damaging effects of rising damp.

2.4.1 The Effects of Ventilation and Humidity Control in a Historic Building

A recent scientific research study (Baker, C. et al., 2007) was undertaken by the University College of London for the Engineering Historic Futures project. This project involved a field monitoring case study on Blinking Hall in Norfolk. The basement of this building has a history of flooding and resulting algae problems which are causing serious internal damage within the building (see Figure 7).

Figure 7: Damage incurred in Blinking Hall basement due to flooding and continued moisture presence (Baker et al., 2007)

The study involved the careful analysis of the materials in question and the affecting environment. Monitoring techniques included the measurement of moisture content using wooden dowels inserted into predrilled wall holes, the monitoring of surface temperatures, room temperature and relative humidity. Additional climate data was collected using an onsite weather station.

In response to the identified problems, tests were set up to analyse the buildings response to changes in its climatic environment with the following stages:

- Air was circulated through the basement area from adjacent corridors
- Certain areas of the basement were partitioned off to reduce air exchange
- Tanking and plaster were removed from a specific area of wall. These were then enclosed and de-humidified.
- Lastly, the enclosure and de-humidifier were removed.

Before partitioning, the area responded to the external environmental conditions, with the wall remaining in the same condition due to the ample supply of moisture from the underlying soil and the moisture dowels registering high moisture content readings (almost maximum after installation).

After the selected section of wall was partitioned, it was noticed that by reducing the air flow through the room that the walls moisture problems intensified. The room temperature increased and even though the relative humidity decreased, the moisture content increased (by almost 20%). The dowel monitors registered maximum moisture content and the walls remained saturated.

The de-humidifying intervention technique had the biggest influence on the conditions of the basement with a significant reduction in the moisture content (which almost matched the exterior humidity). Surfaces were seen to dry out significantly and this was also reflected in the dowels.

Finally, after removal of the de-humidifiers and the partition, the conditions promptly returned to the pre-test conditions.

These test results illustrate how changing the internal climatic conditions (reducing ventilation and instigating de-humidifying), heavily influence the behaviour of the walls. De-humidification had the greatest effect on the walls conditions but was short lived since pre-test conditions returned almost immediately after the de-humidifier was removed. Additionally, the testing illustrated the benefits of ventilation and the adverse effect of containment (Baker, et al., 2007).

2.4.2 Mortars for Repointing and Rendering

Recent studies on a similar tower house in West Ireland have yielded interesting results regarding the use of traditional mortars. Ardamullivan Castle is a six story 16th century tower house located near Gort in County Galway. Ardamullivan attracted significant attention due to its moisture infiltration problems and the damage which was being done to interior paintings on the original plastered walls. Pavía (2005) outlined several studies of the original lime mortar in place in Ardamullivan and conducted research into repair mortars to be used and chosen for the restoration project. The original pointing mortar and the stone masonry were studied by means of analytical techniques and laboratory testing methods which measured porosity, densities, compressive strength, capillary suction and water absorption in accordance to relevant standards. The analytical techniques included the use of petrographic microscopy and X-Ray diffractometry (Pavía S. , 2005).

Pavía's studies recommended a replacement mortar similar to the original mortar which was entirely compatible with the surrounding studied masonry units. A formulated magnesium lime mortar was chosen for the final restoration mortar, due to its compositional and behavioural closeness to the original mortar used in the castle, and its favourable compatibility with the pure carboniferous limestone masonry units (95% calcite with 5% inert quartz). Also, in a separate and more comparative study, the magnesium lime mortars proved to be the superior to other tested binders (such as feebly-hydraulic mortars) in areas subject to the presence of moisture (Pavía et al, 2006).

Lime mortar is an ancient material that has been used in construction for millennia, with some records showing the use of lime mortar in Palestine and Turkey as far back as c 12,000 B.C. (von Landsberg, 1992) It uses journeyed through the Greek and Roman empires and was used until the 21st century. However, in the mid-19th century, with the invention of Portland cement, the use of lime mortar drastically declined in favour of Portland's strength, quick setting times and durability. However, over time it was realised that Portland cement was inappropriate and incompatible with many historical structures due to its hardness, lack of flexibility, its damaging salt content and its impermeability. Due to these findings, there has a been a renewed interest in the use of traditional lime based mortars, however, the complex mixes and mortar designs specs have been lost over time. Unfortunately, in the last few decades, very little research has been conducted on traditional lime based mortars, and there is a lack of knowledge regarding their characteristics or their properties.

Properties such as long carbonation time durations, weak mechanical properties, low internal cohesion and high porosity led to the decline in use of lime mortars. However, a recent study has delved into this area with the intention of improving the characteristics and properties of the lime mortars through the addition of select additives (Ventolà et al., 2011).

The study involved the mixing of six different mortars with different traditional organic additives and were analysed afterwards in the laboratory to assess their new properties. The six mixes were as follows:

- Lime + aggregate (river sand) + water (blank sample)
- Lime + aggregate (river sand) + water + animal glue (protein)
- Lime + aggregate (river sand) + water + casein (protein)
- Lime + aggregate (river sand) + water + nopal as powder (polysaccharide)
- Lime + aggregate (river sand) + water + nopal as mucilage (polysaccharide)
- Lime + aggregate (river sand) + water + olive oil (fatty acid)

The results were very impressive indeed and the conclusions derived from the study were as follows:

The addition of the animal glue protein increased the lime mortars mechanical strength by a factor of 2 (and probably more since it was tested after a 28 day curing length). The carbonation time was improved by a factor of 2 also with the addition of the nopal (both as powder and as mucilage) to the lime mortar.

Most importantly, for the area regarding moisture protection, the addition of olive oil to the mortar mix reduced the pore system by half (in percentage of volume) and decreased the pore size. Additionally, the addition of olive oil improved the impermeability of the mortar. This is an extremely important result since normal lime mortars can be quite porous leading to serious moisture problems (as discussed earlier). By adding a natural organic fatty material, the porosity is reduced and thus the ability of the material to resist water intrusion. The addition of animal glue was also beneficial on this front as it reduced the pore size but not as significantly as the olive oil (Ventolà et al., 2011). Finally, the study showed that the lime mortar mixes which were made were suitable for repointing, new joints, rendering and various other uses. Due to their natural make up and organic additives they are suitable for historic building repairs and are compatible with traditional building materials.

This study conclusively underlines the benefits of lime based mortars and the addition of natural additives for the improvement of their properties and characteristics. This is of particular interest to restoration studies and projects in European countries that receive higher levels of rainfall and experience more serious problems with regards moisture intrusion, as is the case in Ireland.

These studies and researches have all benefited the preparation for a well-informed, state of the art analysis of the moisture problems at Barryscourt. By understanding both the scientific behaviour of moisture in masonry and the most traditional and up to date remedies and solutions, a comprehensive approach can be followed to accurately and extensively identify the problems and help lead to intuitive solutions and intervening procedures at Barryscourt.

3 THE IRISH TOWER HOUSE

3.1 Origins and Development of the Irish Tower House

Ireland's countryside and towns are dotted with castles, quietly standing testament to the long and turbulent history which generated their existence; a history documented in stone.

There has been much discussion regarding the true origin and impetus for the development of the tower-house, with conflicting ideas and theories for its intended purpose in Irish society.

From the end of the 12th century onwards, due to the domestic unrest between rival clans and provincial leaders and the subsequent Anglo-Norman invasion, the development of castles accelerated with the increased threat of attack and need for defences. Fortifications became all the more common in order to secure and defend one's property and governing region, with the tower house a central point in these strongholds. Harold Leask was one of the first to argue that a £10 grant offered by King Henry VI in 1429 was the initial incentive to encourage settlers to construct small towers to fortify their lands within the Pale (English governed region surrounding Dublin, East Ireland) (Leask, 1941). Barry has argued that the origins of the early tower house stem from the 14th century fortalice (Barry, 1993) and strengthened his argument by adding that the tower-houses might be a compromise between early large stone fortifications and later less fortified manor homes of the 16th and 17th century (O' Keefe, 1997).

(Sweetman, 2000) agrees with these studies to an extent but states from his studies, in conjunction with the known & recorded archaeological sites of Ireland that the early tower castle sections stemmed from early smaller castles known as hall-houses. These seigniorial castles were generally poorly defended buildings in isolated locations and dated from the 13th century although some examples from the 14th century also exist. (Sweetman, 1999) These constructions were basically comprised of a two-storey structure with a well-defended ground floor and a first floor hall with the entrance at that level. This hall would be used for meetings of the lord and his subjects, and for private banquets and dealings. The floor above this level would enclose the private living quarters of the owner and his family. These hall-houses are known to have an adjoining tower, known as a service tower which contained access stairways, the solar (resident's private quarter, usually a smaller comfortable room) and the adjoining bed chambers: a definite predecessor to the later tower-house. They are not too dissimilar and sometimes these hall-houses are easily confused with later tower houses due to their common resemblances. The main differences between these early period castles or hall-houses can be identified when one examines the construction details that evolved over time and separated the two castles in distinction; the most important being that the entrance was always at first floor level in the hall-house. Those designing and constructing later hall-houses also began incorporating projecting towers from their structure, which was a typical element of the tower house. Also noteworthy is the fact that early hall-houses had wooden floors, and at a later stage this was replaced with earth and stone vaulting, another defining feature of its descendant. They also advanced the hall-houses by adding stories during the later periods of their use, increasing their height and vantage points whilst also adding defensive features such as bartizans (a small overhanging turret projecting from a wall, parapet, or tower) which were yet another feature of advanced tower houses in western Ireland (Sweetman, 2000).

By examining these studies and clear progression of castle design it becomes evident that the hall house was an inspirational guiding prototype which led to the tower houses' eventual birth.

3.2 The Irish Tower House in Detail

As outlined above, the most common type of castle in Ireland is the typical Irish tower-house, which is considered the quintessential Irish castle of the late medieval era. These tower houses are typically found in positions of strategic importance, overlooking the surrounding regions which were controlled by its inhabitants and underlying their power and status. Although tower houses are located all over the Irish countryside, their distribution is more concentrated near areas of rich pasture and fertile lands (Leask, 1941). (See Figure 8)

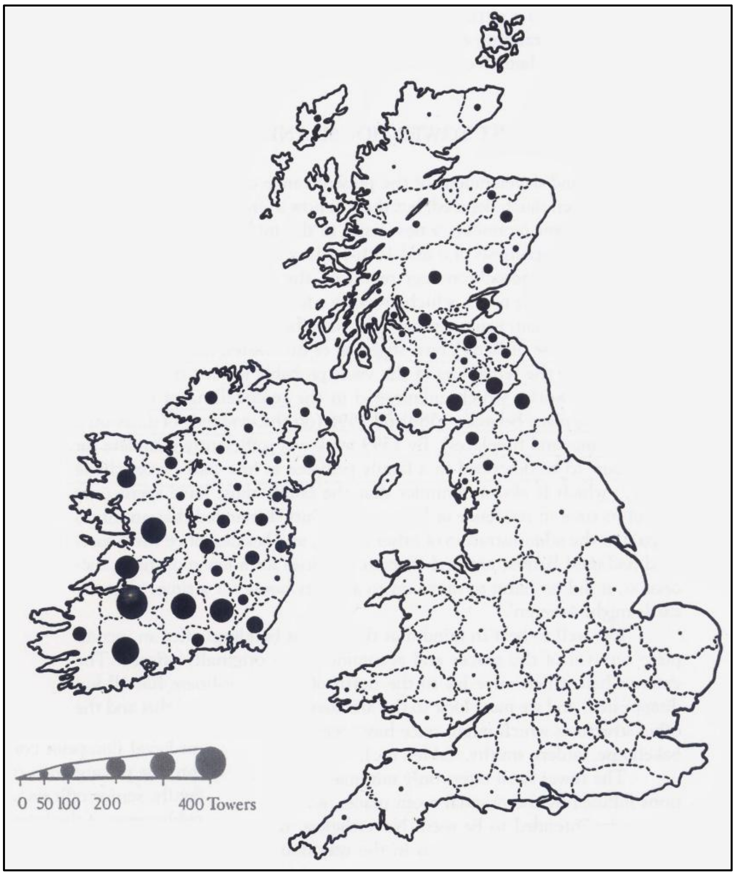


Figure 8: Map indicating distribution of Tower Houses over Ireland and Britain (Smith, 1988)

These constructions evolved over time moving from smaller simpler rectangular towers to complex well defended strongholds and had been adopted by both natives and settlers alike by the end of the 15th century (O' Keefe, 1997). Although the tower house is the most common form of castle found in Ireland, they also happen to be the last understood of all Irish castles (Sweetman, 2000).

Most historians and archaeologists generally agree is that the tower house developed from early simple rectangular example towers which were mainly located on the eastern side of the country near the Pale, and that their construction was greatly encouraged by Henry II's grant. These structures spread out and were adopted by all as they spread through the landscape, becoming more sophisticated and commodious in design as they progressed. The early examples of the Irish tower house in the eastern half of the country tend to be of a simpler design nature and date from the earlier development stages of this type of castle, such as Roodstown Castle in County Louth (see Figure 9a). These also usually exhibit projecting towers on their angles and are less developed in the discipline of effective attack-deterrent defences such as bartizans and running machicolations as found on the western developed tower houses or the west and south-west. These castles from the midlands, as seen by Clara Castle in County Kilkenny, (see Figure 9b) and western reaches of Ireland can be associated to the later stages of the tower-houses development due to their sophisticated and layout - a fine example of this advanced type of Irish tower house resides at Blarney, perhaps the most famous of all Irish castles (see Figure 9c). These later structure had the added feature such as detailed interior design and decorations, advanced defence systems and the increased attention to the comforts of the habitants. These comforts owe to an increased sense of security since the windows are larger than earlier examples, fireplaces feature more and more with ornate surroundings. Some of the tower houses of the west also have simple towers like those of the east but they possess substantial, well defended surrounding bawn walls and gatehouses (Sweetman, The Barryscourt Lectures I-X, 2000, p. 286).

(a) (b) (c)

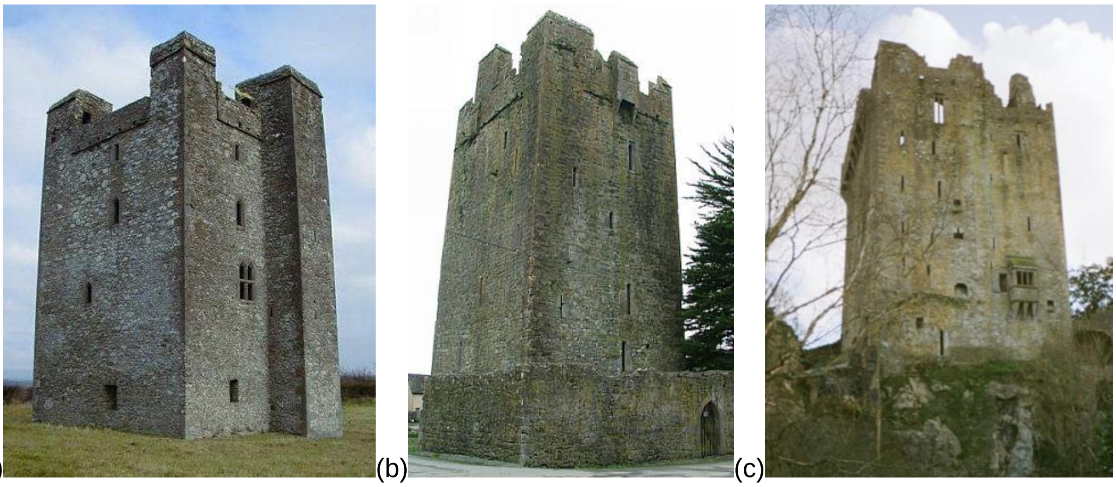


Figure 9: Irish Tower Houses - Roodstown Castle (McElherron, 2000), Clara Castle (S., 2006) & Blarney Castle

Overall, the tower house placed security above comfort, and the primary role of the castle was defensive, both as protection from pillaging enemies and as a secure base from which the inhabitants could launch cattle-raids of their own on rival clans and neighbours.

3.3 Barryscourt Castle

3.3.1 Location

Barryscourt castle is located just outside the small rural village of Carrigtwohill, County Cork, Ireland (Figure 10). Its strategic location lies almost halfway between the towns of Cork and Youghal, two important ports and economic epicentres of the southern Irish coastline, and alongside the medieval route to the monastic site of Cloyne. The archaeological study also revealed that the early fortification had a small L-shaped moat near the northern western region of the site which played a minimal defensive role and was probably channelled water for the storage of live fish. The lands to the south and west of the castle were covered by tides until the 19th century and it is believed that the original approach to the castle was by boat. Since then, the surrounding lands have been reclaimed and cultivated for pasture and agriculture and the castle now stands at the crest of a very gentle incline with surrounding descending contours assisting drainage to the nearby stream. A detailed topological site survey was conducted and this can be viewed in the annex. It shows the raised location of the castle and the surrounding levels which accommodate drainage from rainfall and a required elevation to escape river flooding.

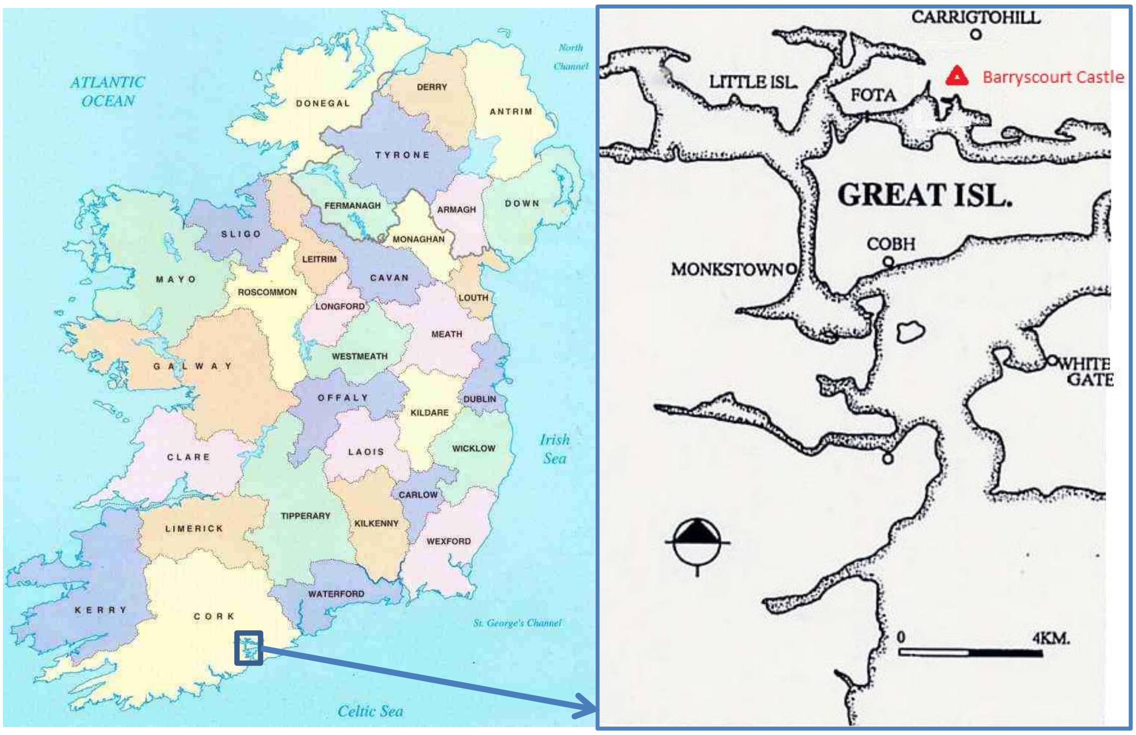


Figure 10: Map of Ireland with detailed location of Barryscourt Castle, County Cork – Zoomed-in map from (Monk & Tobin, 1991)

3.3.2 Local Climate – Weather Conditions

Ireland is notorious for its precipitous environment; as the most westerly country in Europe its dominant climatic influence is the Atlantic Ocean. Accordingly, Ireland does not endure extreme amplitudes in temperature as suffered by other countries at the same latitude, since is it is regulated by the warm North Atlantic Drift. This influential current has a greater effect near coastal regions and reduces along with inland distances. As a result Irish winters are cool and windy, whilst our summers are mostly mild and windy. The topological shape, shelter from surrounding hills/mountains or protective buildings/trees will all have a decisive influence on the wind speeds and intensity for that particular area. For Ireland in general, the prevailing winds are from the south and west for open sites. More specifically, for Barryscourt, with little in the way of sheltering factors, the prevailing wind drives from the west, predominating alternatingly between the southwest and northwest directions (see Figure 11).

For the purpose of this study, information was acquired from the meteorological association of Ireland, Met Éireann. Due to its proximity to Barryscourt castle, the nearby Cork airport weather station was chosen as the source for the weather data which included daily mean temperatures, rainfall amounts, mean wind speeds for the region from January 1962 until the present day. Local temperature and rainfall levels were being recorded in a nearby primary school, Scoil Iósaef Naofa, and the values were obtained in order to check how similar the Cork airport readings were to the readings recorded local to the castle. The readings were deemed satisfactorily similar exhibiting only minor differences. Additional values for the hourly relative humidity of the region were acquired from January 1996 to December 2010, to be used in conjunction with the data loggers monitoring system fitted in situ in the castle by the Office of Public Works, and by the author. The rainfall, wind speeds and humidity readings for the Cork region can be viewed in the annex of this report.

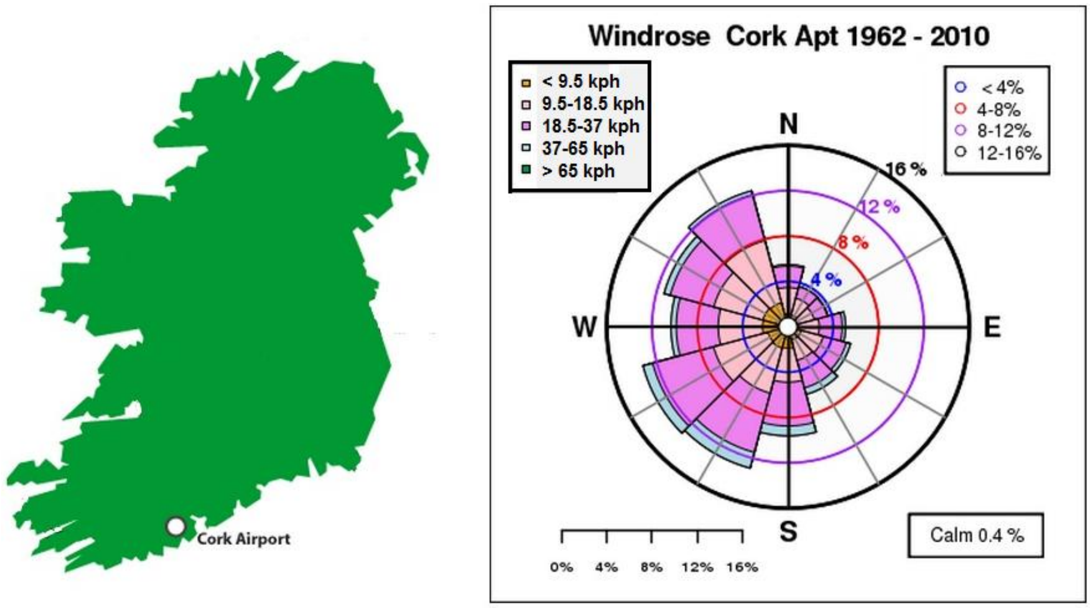


Figure 11: Prevailing wind direction and intensity measured at Cork Airport Weather Station (Met Éireann, 2008)

3.3.3 History

Archaeological excavations at Barryscourt have yielded evidence of a small wooden structure on the site from as early as the 7th century, believed to be the remains of an early watermill which lay adjacent to the local stream (Pollock, 1999). Fragments of a stone and mortar construction were also discovered indicating either a later mill or an early castle. (Chinnery, 1999) explains how that after the 12th century Norman invasion, a prominent Norman family from Manorbier, South Wales, named “de Barris” or “The Barrys” as they are now known, were granted lands in Cork regions as Anglo-Norman influence and control edged westward ousting Gaelic chiefs and families in the process. A charter of King John shows records of a manor controlled by the Barry family in the Carrigtwohill area in 1206. The Barrys established their main seat at this site and became a very prolific and powerful family in the region. During the 14th and 15th century, the family tree flourished and as with many other Anglo-Norman settlers they eventually intermarried with many of the native Gaelic families acquiring Irish names and customs. Violent unrest was inherent in the country at this time and it wasn’t long before the lives of all successors to the seat of the Barry seat were claimed by rival Gaelic and Norman neighbours, leaving the Barrys main line of descent fall to an only daughter. Eventually, in 1556, the lands were passed to a distant cousin, James FitzRichard, of the Barryroe branch of the Barry family. Due to his support of the Desmond rebellion, James was imprisoned in Dublin castle and died there in 1581. His son David had the family castles destroyed to prevent them falling into the hands of the English and the main seat, Barryscourt Castle, was “defaced and despoiled” to prevent Sir Walter Raleigh and his English troops capturing it and using it for its defensive purposes. The following year, David Barry was pardoned by Queen Elizabeth and he soon set to restoring his repossessed Barryscourt castle. He was married and remained loyal to the crown in 1601 when Hugh O’Neill passed by destroying lands on his way to the attempted relief of the trapped Spanish troops in Kinsale, County Cork. As the last head of the Barry family to occupy Barryscourt, David died in 1617 and his succeeding grandson married a daughter of the Great Earl of Cork and relocated to another Cork town of Castlelyons (Chinnery, 1999). Barryscourt was captured by Cromwellian troops during the confederate wars in 1645 suffering cannonball damage during the siege, but their stay was only temporary serving as a military garrison. In the 18th century the castle and surrounding land were purchased by the Coppinger family who built a new house close to the tower house (O' Keefe, 1997). The family eventually deserted the castle and had the roof removed in the early stages of the 20th century when a roof tax was introduced for secondary properties by the government. Landowners who owned more than one abode had to pay a tax per roofed building in their possession so many of those had the roofs removed to avoid paying this levy. Of course, this caused a serious acceleration of deterioration of the affected buildings, and Barryscourt was no exception.

In 1987, the Barryscourt trust was established with the intention of conserving the iconic structure, enhancing the building itself and developing the site for its heritage value and as a cultural asset. In 1991 a detailed architectural study was conducted and documented by Monk and Tobin who described the architectural features, construction phases and stages of the castles development and made recommendations for its restoration and conservation (Monk & Tobin, 1991). The restoration of the castle was completed in 1996 and was carried out by the Office of Public Works who continue to manage and maintain the building to date. Today the castle is open to the public from June to October.

3.3.4 Defining Features of Barryscourt

To this day, County Cork has over 300 tower houses surviving to some extent, of which Barryscourt is a particularly large and well-detailed example (Chinnery, 1999). When considering its defining feature, the tower house, it ranks among the top of late-medieval buildings both architecturally and functionally (Monk & Tobin, 1991).

When judged on stylistic grounds, Barryscourt tower house dates to the middle of the 16th century. The building is constructed from limestone masonry units bound with traditional lime based mortar. Flooring, support joists and the roof structure were built from oak timber sections. The tower house sits as was typical for these structures, within a surrounding protective boundary wall known as a bawn wall. This bawn wall enclosed the tower houses gardens, cattle and smaller dwellings and at Barryscourt the tower house itself acts as part of this boundary wall overlooking the main entrances to the enclosed region. It comprised of a central block with asymmetrical projecting turrets at each corner of the structure, with exception of the north-west corner which does not have a protecting turret. The south eastern turret finishes flush with the outer protective bawn wall and the other two turrets of the south west and the north east sit opposite each other diagonally with differing design. This asymmetric design in both plan and elevation is different to those later tower houses such as Bunratty Castle in County Clare, Ireland; castles which were designed later tended to progress to symmetric shapes to emphasise the aesthetic beauty of the building, further underlying how Barryscourt was constructed to maximise its defensive features rather than compromise safety for symmetrical aesthetical pleasing features (see Figure 12).

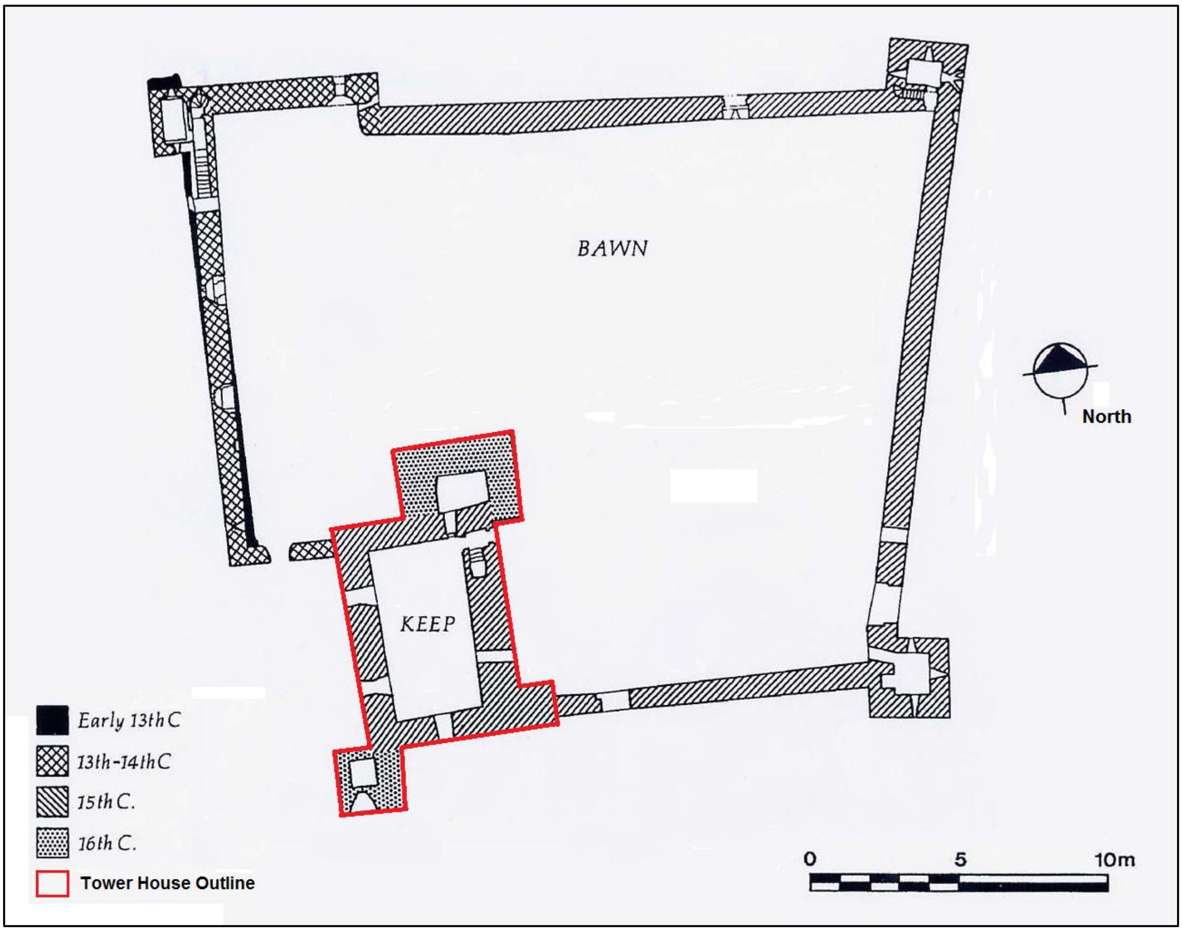


Figure 12: Plan layout of Barryscourt Tower House and outer bawn wall - Adjusted sketch from (Monk & Tobin, 1991)

At its highest points, the castle stands at 25.5 metres in height (not including chimneys) and has the form of a basic rectangle in plan. This rectangle was not laid out based on fickle ad-hoc measurements but rather follows an accurate mathematical proportional layout following the golden section (Golden Section Proportionality – 1:1.618; the buildings length is 1.618 times its width). This proportion was widely used in the design of buildings for rectangular layouts and was used by masons throughout Europe when outlining boundary lines for rectangular base shape (O' Keefe, 1997). This method involved marking out the outline of a square, dividing this area into two equal sized rectangles; marking the diagonal of one and using a rope, swinging the diagonal down until it meets the extended baseline edge of the original square (see Figure 13).

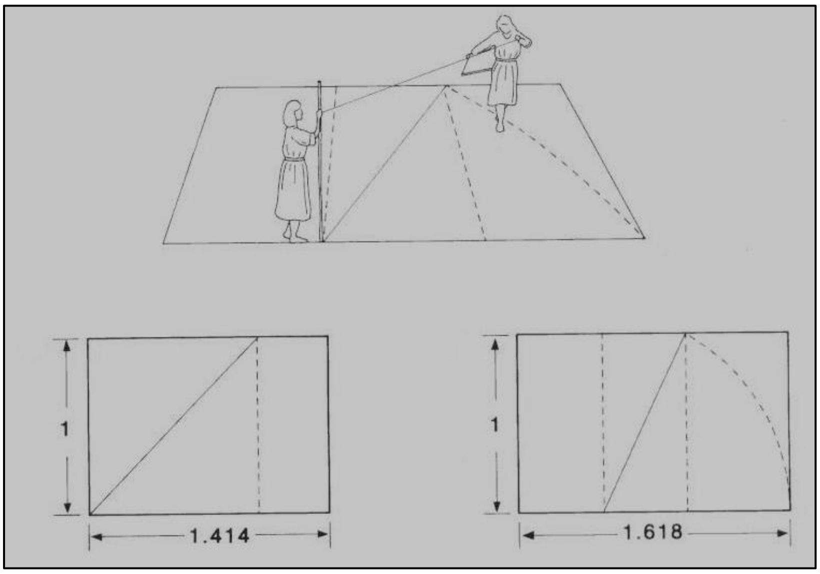


Figure 13: Onsite plan layouts of proportional rectangles, 1:√2 and 1:1.618 (the Golden Section) - (O' Keefe, 1997)

The resulting rectangle is a mathematical proportioned 1:1.618 shape, the geometric expression mapped out by the masons. These medieval masons may not have necessarily known the mathematics behind their methods; that they were expressing geometrical irrational numerical proportions. It however exhibits that they were knowledgeable regarding whole number ratios such as the golden section (as studied by mathematicians including Euclid and Fibonacci), 1: √2 and other ratios (O' Keefe, 1997).

The tower house has three main floor levels comprising of the ground floor (used mainly for storage and defence), first floor (arguably used for semi-public meetings and banquets) and second floor (Great Hall – reserved for family and special guests) with flanking wall walks above (Chinnery, 1999). The three prominent projecting turrets of the south west, south east and north east at the corners of the main block contain the ancillary chambers of the castle including private chambers, storage rooms, latrines, administrative rooms and observation posts. These corner towers have multiple floor levels with some corresponding to the main floor levels while the others relate to mezzanine levels (Monk & Tobin, 1991).

The castle also possesses typical tower house defensive features such as a murder hole (a hole overlooking the main entrance used to survey entrants to the castle and to allow the high ground attack of invaders), a staircase with irregularly sized steps to hinder fast ascent from attackers and a dungeon accessed originally only through a trap door from above.

The main door to the castle is on the eastern face of the ground floor (see Figure 14). The tower house entrance opens into a small lobby and on into a rectangular flagstone based room, with access on the north side to the dungeon and the main stairwell which runs to the first and second floor. Primarily used as for storage and as an important main defence room, it is heavily guarded in its design with thick batter walls (up to 2.75 metres thick in places) and narrow slit windows with little ventilation. The timber ceiling is held up by oak beams which rest on the projecting corbel stones at regular intervals throughout the room and also acts as the flooring for the hall above.

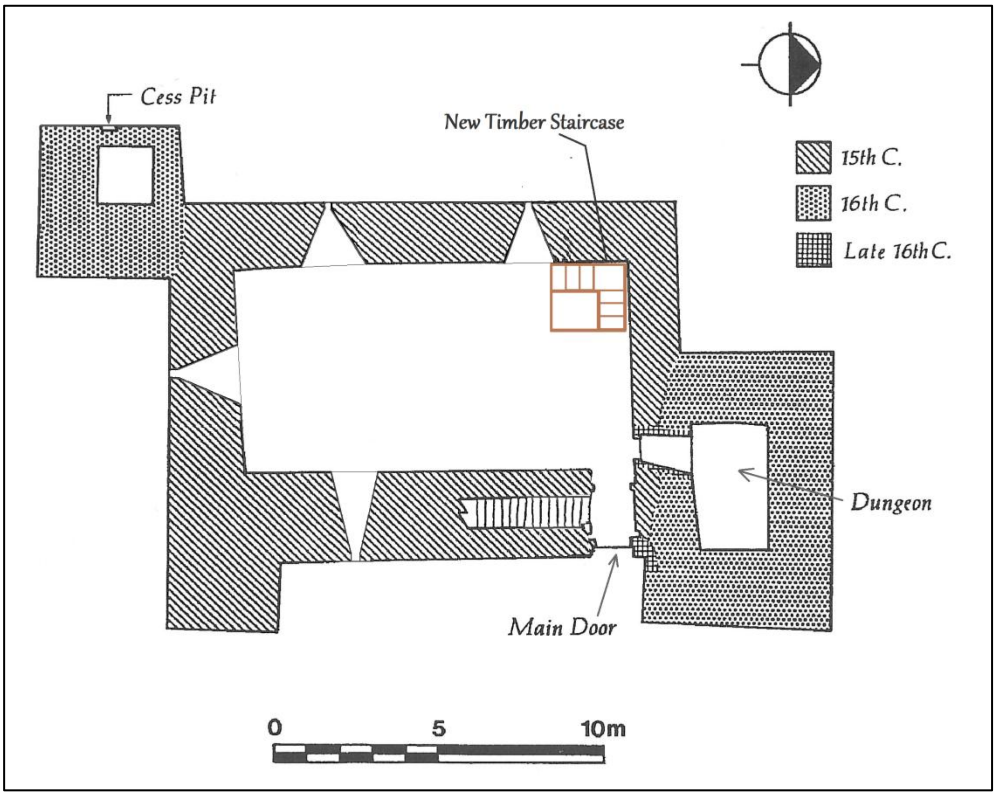


Figure 14: Plan view of ground floor in Barryscourt Tower House - Adjusted sketch from (Monk & Tobin, 1991)

Access to the first floor is now be made via the main stairwell (which is presently closed with an iron bar gate), or by a short winding timber stairwell which is situated at the north western end of the ground floor and opens at the northern end of the next floor. Originally the only entrance to this floor would have been halfway up the stairwell – the original door is still in place.

The first floor hall consisted of the semi-public hall which was used for business meetings, feasts and banquets with guests and esteemed members of the public. This room features a large central fireplace on the western wall with an internal wall flue which rises through the tower house instead of rising to a chimney (see Figure 15). The hall includes only three small windows for natural light; artificial lighting now helps to illuminate the room similarly as is done in the ground floor. The ceiling consists of a barrel vaulted roof, which was constructed in the later stages of the 16th century after the original pointed vault either was replaced or collapsed. The pointed gable profile of the earlier vaulted ceiling is still visible on the southern wall. All rooms adjoined to this main room are also vaulted and are accessed through small doors/passages. A door on the southwest corner of this first floor hall all leads to the large garderobe (medieval toilet), whilst a door on the southeast side leads to a defensive room overlooking the bawn and castle entrances. On the northeast corner, a passage leads past a smaller garderobe into another small room with a fireplace (now reconstructed kitchen) and down to the room overlooking the main castle entrance, complete with murder hole.

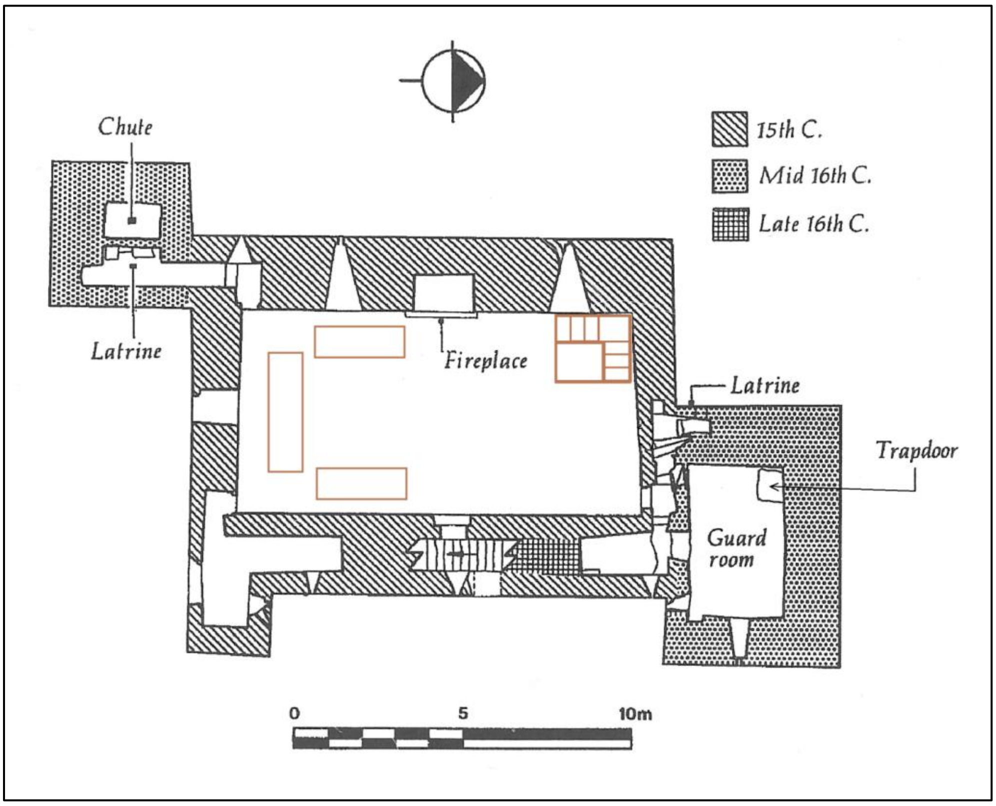


Figure 15: Plan view of first floor in Barryscourt Tower House - Adjusted sketch from (Monk & Tobin, 1991)

The barrel vaulted ceiling of the first floor supports the flagstone floor of the second floor level. This room is accessed via the aforementioned stone main staircase, which opens into a grand and more ornate hall (Great Chamber). This hall was reserved for use of the family and important guests with many decorations and the finest of tapestries, furniture and furnishings (see Figure 16). An impressive fireplace with a carved and dated (1588) mantel dominates the room, again on the western wall side, yet this fireplace leads up into a main chimney outlet. Originally a timber gallery/garret-story would have overhung the great hall as the original support corbel stones are still in place at regular intervals along the walls.

A passageway in the southwest corner leads to additional large garderobe and a spiral staircase which leads to two further rooms and the roof of the south-western turret. Barryscourt also possesses its own small chapel accessed through yet another intricate passageway on the northeast corner of the Great chamber. Evidently a chapel due to its ornate features including carved window frames, an altar and evidence for a quatrefoil piscina in the sill of the window surround along with traces of wall and roof paintings. The chapel adheres to the pre-requisites for a chapel incorporated into a building; it is aligned east-west and is located over an entrance, respecting international architectural tradition (Pounds, 1991).

This passageway also leads to a winding stairway giving access to the master bedroom (bottom right of Figure 16) and onwards further to a small opening to the roof wall walk and the roof of the northeast turret. The decorations of this bedroom are tell-tale signs indicating it as the master chamber. According to the status of the room and the intended inhabitants of that quarter, are the wall openings. Windows and doors become far more ornate and elaborate in rooms such as in the master bedchamber, and the social order or class can be easy identified when one examines these details. The hierarchy of the buildings occupants is encoded in the stone work such as the intricate fireplace mantelpieces (inscribed with the date 1596AD), carved window frames or a private latrine adjoined to the room; all extravagant features of this chamber (O' Keefe, 1997).

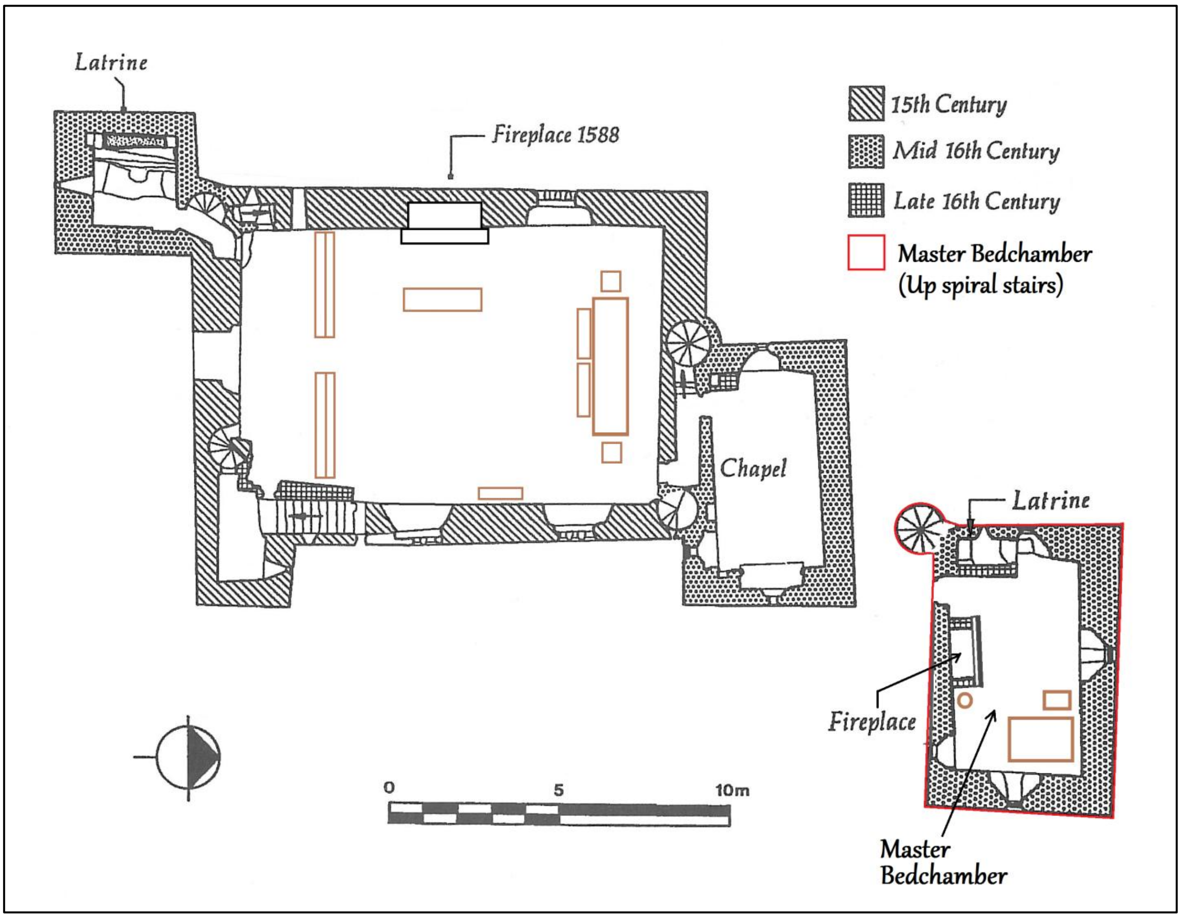


Figure 16: Plan view of Great Chamber and Master Bedchamber - Adjusted sketch from (Monk & Tobin, 1991)

Although little remains of the original flooring in Barryscourt, it is believed that the first floor hall was originally floored with oak boards laid on support joists, as mentioned earlier. Rooms of higher status such as the Great hall, the chapel and the master bedchamber may have had flagstone paving. The rest of the castles rooms would have been most likely floored with rammed earth, overlying the vaulted support ceilings below. Busy passageways and thresholds would have had this same style flooring but would have been complemented with flagstones to ensure longevity and hard wearing. These earth floors were usually comprised of various combinations of lime, clap and plaster with supplementary admixtures of grit, crushed brick, gravel, pottery or whatever was obtainable. It is surprising how hard wearing these compacted composite floors of lime, ash and clay are which also plainly explains their widespread use (Chinnery, 1999).

Irish tower houses, including Barryscourt, possess many slit windows (known as arrow loops) as a defensive feature, and with the lack of glass used in these buildings, alternative methods to prevent water entering in times of rain and wind were developed. In order to help deter water from entering during these conditions, simple timber frames were installed just inside the window openings. These frames would have had animal intestines stretched across them and would have been oiled with animal fat to make the skin more waterproof and also more translucent, allowing additional light enter the interior. In times of rain, the rain would beat against the outside of these skins and drip down inside the window frame, where a downward channel to the exterior was located. This downward spout allowed the rain driven water to exit, with minimal backflow and would have provided ventilation which in turn helped dry out the interior and the internal environment. These openings continue to ventilate the building today and have wire gauze installed to prevent animals from entering.

Figure 17: Original outlet to facilitate drainage and ventilation – Today these outlets continue to provide ventilation to the interior environment – Steel gauze keeps wildlife out

The Great chamber and main block of the castle is roofed with an oak braced and dowelled trussed frame, which was constructed using only traditional joinery and materials, with a felt covering topped with slates. The main block section of Barryscourt is gabled from north to south with all round dripstones for the evacuation of rain water drained from the roof surfaces – the roof is described in detail in the following inspection chapter.

3.3.5 Wall Finishes / Renders / Plasters

Irish castles today stand as monuments to our tempestuous history, primary fortified residences which evolved with each era to achieve additional comfort within the confines of reassuring security. These structures are instantly recognisable for their particular architectural features, striking locations and the intricate stone masonry facades. However, back in their heyday, Irish castles would not have looked as they do today. In his study on the refurbishment of Barryscourt (Chinnery, 1999), explains the standard procedure for late-medieval stone buildings and the treatment they gave to the walled surfaces. This practice was to have all stone surfaces to washed-over with a lime, lime casein or distemper type paint. The quoin (corner stones) and ashlar surfaces would have been treated as so, whilst the rubblestone walls had layered applications with a primary coat of rough-textured lime mortar mixed with hair, fine gravel and various other material. This would then most probably been covered with a final coat of finer lime plaster bound with hair (to prevent the effects of shrinkage).

The external stone surfaces would have been covered in their entirety to help protect the underlying stonework from the elements, colouring and highlighting the building as a landmark status symbol. In the case of the interiors, the walls were also painted to allow more light to be reflected into the interior spaces and to somewhat sanitise the dirty and smoky environment within. Chinnery goes on to explain how these finishes were considered a sacrificial layer which protected the stone from weathering from the precipitous environment and everyday wear and tear. These layers unified the interior and exterior surfaces and were cheap and easy to renew. Luckily, in Barryscourt castle, portions of the original wall render survive to this day. All walls of the chambers, halls, stairs and passageways of the castle show evidence that almost all surfaces were finished with a smooth coat of render, which includes all sections of the stone structure such as the detailed quoinwork surrounding the doors, windows and fireplaces. This render would have been used extensively throughout the whole structure, covering even the most detailed of carvings and clear pieces of this surviving render are visible in the more elaborate stone work in the Great Hall and the master bedchamber. Even where the rendering has fallen off or been lost over the years, the stone surfaces show deliberately etched pits which were chipped into the stones by masons. This rougher surface would allow the rendering mortar to adhere much more easily and effectively to the stonework. Further evidence for the extensive use of this rendering plaster is visible in sheltered sections, such as on the roof soffits over the main stairwell, regions that escaped most of the weathering and deterioration from the years of dereliction. In some sections, an underlying pale limewashed finish has been become visible after sections of the overlying original render have fallen off. This would have probably been first applied as an undercoat finish to help increase the bind between the wall the render application. Experts deny this was ever used as a decorative finish, but wholly intended as a functional layer.

As outlined before, limewash would have been used extensively throughout the building to help distribute what little light was allowed in through the small windows and to brighten the interior by whitewashing both walls and stonework as one entire surface. Surviving historical papers have documented the instructions for “whiting the walls” in Kilkenny Castle, Ireland in 1668 (Salter, 1993). This practice is believed to be widespread and although Barryscourt castle does not much direct evidence for limewashing on wall surfaces of the building, but this lack of evidence does not imply that the renders were not whitewashed due to the fact that such lime coats degrade quickly under harsh weathering such as Barryscourt endured. It is believed that all walls of the building would have been limewashed (or washed in other colours) extensively and regularly, with new replenishing layers building up over older layer over the years. Other castles have extensive proof for this practice and even though Barryscourt has suffered over the years of its abandonment, surviving decorative paint sections have been found in the Chapel walls and ceiling (Chinnery, 1999). What can be firmly established and understood is that the use of internal renders and limewashes was universal in stone buildings (Powys, 1996).

The exterior walls of the castle would have had a protective rendered surface also, quite similar to the interior render, but with a courser and more durable mix of lime, sand and hair and other binding material. There are some surviving small sections of the original render, especially on the north facing walls. The outside walls would, just like the interior, have been regularly whitewashed to help protect the underlying surface, slow water infiltration and also highlight the buildings position and status in the locality. Various historic records along with medieval poems and songs have been known to refer to castle’s bright appearance, and how they stood out against the surrounding rural landscape.

3.3.6 Previous Restoration Project and Barryscourt Castle Today

The Barryscourt Trust was established in 1987 with the intention of conserving the remains of the original castle, enhancing the castle itself to restore it somewhat to its former glory and developing the surrounding site to make it accessible and appeasing to visitors. This Trust organisation raised awareness about the cultural importance and historical significance of Barryscourt castle, and the building was recommended for a full restoration project which began in the early 1990’s. The government organisation, Dúchas - the Heritage Service took on the task and the restoration project was completed in 1997.

At the beginning of the project, the castle was in very poor condition; large scale water damage due to no roof protection had caused severe weathering of all main floors. Biological activity was thriving in the abandoned castle – vegetation such ivy and small plants had run riot on the walls, with strong roots rife in already vulnerable cracks in the both the interior and exterior (see Figure 18).

(a)  (b) 

Figure 18: Photographs of Barryscourt from the southeast in 1914 – note the original roof still intact in this period (OPW Archives, 2011)

The lower sections of the castle walls had severe mortar loss, due to plant roots working their way into the lime mortar and rising damp was also evident from mortar loss and deterioration in areas where plant life was not so threatening. The ramparts had disintegrated and collapsed around the castle and many of the fallen masonry had been claimed by locals for walls and new buildings; there was extensive material loss as seen in the various historical photographs in Figure 19.

(c)  (d) 

(e)  (f) 

Figure 19: Photographs of the deterioration of Barryscourt through the 20th century: (a) View from northeast; (b) View from southeast; (c) View from southwest; and (d) View from west (All acquired from OPW Archives, 2011)

Numerous holes were dotted over the building, some due to material disconnecting from the surrounding blocks and others due to deliberate human destruction. Vandalism had its part to play in the deterioration of the tower house also; spray paint, paint, and etchings were widespread, some of which sadly are still evident to today. Thieves had made attempts to steal the magnificent carved mantelpiece from the Great Hall on the second floor and had cracked a significant section of the fireplace away from the wall. They also broke several large holes in the walls to allow them to throw looted pieces outside. Window sills and carved surrounds had been removed and remaining smaller sections had fallen out of position or out of the building. Several surrounding stone features in the garden were also removed; large stone blocks which were originally used as drying stone tables for straw or corn were taken from Barryscourt castle and now prevent cars entering Carrigtwohill graveyard.

The external mortar was in very poor condition; mechanical weathering from the wind and rain had taken their toll and without a roof and effective drainage from the tops of the walls damage accelerated drastically, cracks between stones and mortar were clearly evident and the mortar loss was widespread.

The restoration began with the clearing of the site; detached masonry blocks, stones and disused material of no historical significance were all removed to landfill. Trees, bushes and various other damaging shrubs which had grown alongside the walls were removed to expose the hidden stone walls behind them. Their roots which had become embedded in the castles masonry were carefully cut or poisoned in order to minimise mortar damage and ensure the safe removal by not upsetting surrounding blocks.

Fallen material was gathered to provide suitable stones for the repair of wall holes and damaged parapets. Doors and window pieces such as the carved stone mullion window surrounds were remade and installed in their original positions. The oak, flagstone and rammed earth floors were redone adhering to historical evidence for the tower house's original typology. This respectful consideration for the historical architecture and original features of the castle is evident from the restoration efforts and achievements.

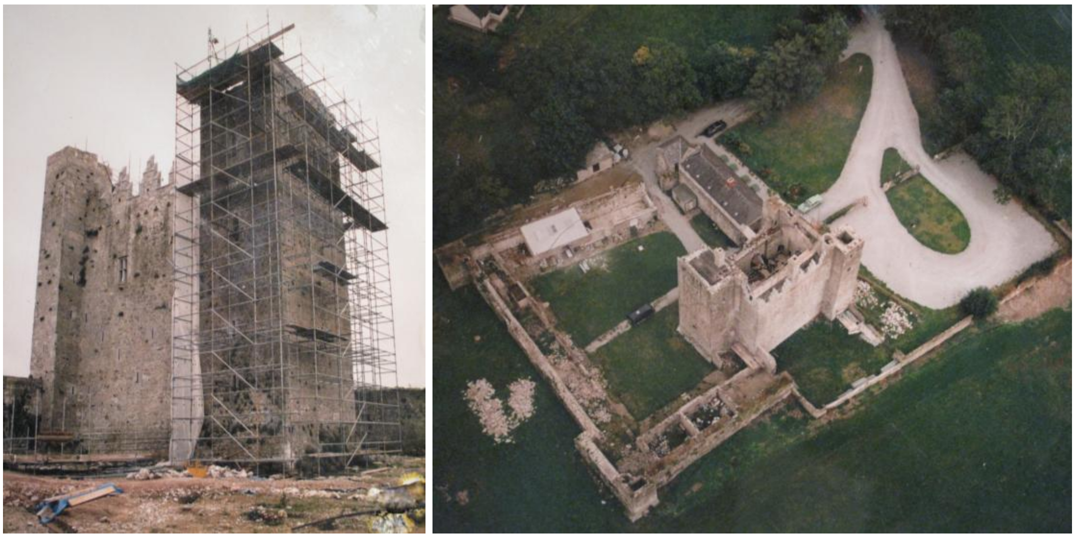


Figure 20: Barryscourt restoration in progress (OPW Archives, 2011)

The building was reroofed during the winter of 1997 and was built using traditional dowel and jointed oak timber sections by skilled carpenters working on behalf of the Office of Public Works. This timber framed roof unfortunately had to endure a harsh winter and despite the workers best attempts to protect the new frame from the elements during a vicious storm during Christmas week, the timber fell victim to the driving rain and remains water-stained to this day. This was an important piece of information when the rooftop visual inspection was carried out. A detailed study on the roof surfaces and drainage system is outlined in the roof inspection which can be found in section 4.3 of this thesis.

At the end of 1999, the building was reinstated with 16th century period furnishings based on evidence on the material culture of the landowning classes in Munster (Southern province of Ireland) during the period 1450 to 1650. This furnishing was established to help recreate and reinstate the typical domestic interior of the castle from its heyday. The castle also had underground heating installed on the ground floor which is seldom used due to its expense and is typically only used in times of severe weather conditions to allow the building to “dry” somewhat.

The restoration of Barryscourt also included the development of a 16th century style privy garden within the perimeter of the bawn wall and an original orchard has been restored in the adjoining field. The castle is now open to the public and tourists, during the months of June to October, and is run by the Office of Public Works. Hourly tours operated daily from Monday to Saturday, access is by guided tour only and admission is free of charge.

3.3.7 Details of Restoration Render and Mortar

Since the survival of intact limewashed interiors from this era in Ireland is unknown, and examples in England are very rare, the restoration crew turned to an English original chamber in Somerset as the interior model for Barryscourt tower house. The surviving Somerset interiors included a group of untouched and unaltered limewashed interiors dating from the 16th century with finishes that correspond favourably with evidence found in Barryscourt and similar Irish buildings. The English walls were plaster-rendered over rough masonry, with the surface of the render finishing flush with the quoin stones of the fireplace, windows and door surroundings. Their cream coloured wash is used over all surfaces, including stone, plaster and wood, unifying all areas and accentuating finely moulded features as seen around fireplaces and doors. Over the years, dampness has forced the quoin stones on the corners to become recognisable from the other regions, but this would not have been the original case.

The restoration project at Barryscourt has used a selection of lime mortars for the repointing of the castle. When the repair project commenced, the mortar of first choice in restoration work was a lime mortar which was gauged with cement. This comprised of a delicate balance of sand, lime (hydrated) and ordinary Portland cement (OPC) with a ratio of 9:2:1 respectively. This mortar proved to be quite effective but only as long as the mixing was done very carefully to ensure a correct ratio of ingredients, in order to avoid complications arising from the use of cement in historical buildings (sourced from information provided by the Office of Public Works, 2011).

The more recent repair work executed at Barryscourt has used a more up-to-date natural hydraulic lime mortar (NHL 3.5) for the majority of the external walls. This mortar is used principally for masonry bedding, pointing and the intermediate and top coat of rendering, normally in the proportions of 1 of lime to 2 or 2.5 of sand. In the case of the interiors, most of the work was generally done using a lime putty mortar which was gauged with Metastar. Metastar is a highly reactive pozzolan made from purified Kaolin which can be blended with many different types of hydraulic and non-hydraulic lime and is compatible with traditional materials. Surfaces on the interior were additionally washed over using a traditional lime wash which serves as both a decorative, illuminating and sacrificial layer on the walls.

The conservation project involved minor amounts of plastering, and the areas which received this attention were the chapel and the gable end over the master bedchamber. These areas were selected due to their sensitive interiors and to give protection due to their proximity to the prevailing wind and rain directions.

3.3.8 Present Damage/Problems in Barryscourt

Thanks to the Barryscourt Trust foundation and the enthusiastic care and attention that was/is shown to the tower, the building is in good structural condition (see Figure 21). There is no evidence for large scale cracking, all roof sections which had been severely dilapidated are now rejuvenated and structurally sound and the building does not appear to be suffering from settlement issues, compatibility or stress cracking. The cannonball impact damage on the eastern facing wall is purely superficial damage, providing an interesting reminder of the castles bombardment by Cromwellian troops in 1645.

Figure 21: Barryscourt Tower House 2011

. However, despite the comprehensive restoration of Barryscourt, the castle is not without its problems. In fact the building is suffering quite considerably due to moisture infiltration on a large scale throughout the whole structure. It is this damage that provoked this study and the subsequent analysis.

The almost relentless battering from the wind and rain in Ireland is taking its toll on Barryscourt tower house. During the winter and spring months, there is very little time between rainfalls to allow the building to dry out. The building acts as a giant “sponge” during long rain spells and absorbs vast quantities of water. This water migrates through the thick walls, causing havoc on the interior of the building. On many the occasion after long rain spells, water can be seen trickling down the surfaces of the walls and in some cases of extreme rainfall, runs down the stairwells with a steady flow. Apart from the harshly inhospitable environment, this infiltration is harming the building elements and decorations. Original plaster work is detaching, mortar loss is extensive, timber elements are exhibiting deterioration and staining, general staining is widespread and interior decorations such as textiles are degrading rapidly. The observed damage will be expanded upon and discussed in detail in the following section, chapter 4.

This problem is not just in Barryscourt, but is a widespread problem in these types of buildings due to their construction methods and materials, and their present condition (including the present lack of exterior renders and protective layers). Castles all over the country are suffering in an almost identical manner; many are deteriorating to a similar degree but most of the others are not as fortunate as Barryscourt to have had the benefit of a large scale restoration overhaul and reroofing project and their condition is in a far more advanced state as a result of this.

Barryscourt is open for a third of the year, for the more lenient summer months of June to September. The main reason for this short opening term is the shortage of visitors during the other months of the year, and the cost of providing onsite guides for tours. The inhospitable environment during the other months cannot be ignored as another factor to deter the operating governing body from allowing entry to visitors. Barryscourt is suffering from its moisture problems, and lies unexplored by natives and tourists during a significant portion of the year. It is discouraging and saddening to realise that such a wonderful example of medieval life and customs in Ireland is not used to its full potential. The damage inherent in the building is not unstoppable and can be prevented using up-to-date techniques and methods which are entirely compatible with traditional materials and traditional construction techniques and which also uphold present restoration and conservation guidelines and codes.

4 DAMAGE ASSESSMENT–SITE INVESTIGATION

As part of this study, the castle was scrupulously inspected over several visits to identify the key areas of deterioration in the structure and its construction materials. The primary aim of the initial inspections was to isolate the damage suffered by the building, giving a global assessment of the state of Barryscourt castle. Once the damage was inspected and documented the next action was to identify the main locations, and the causes for this deterioration. Damage templates were generated and completed in order to categorise the damage into similar or associated suspected sources. This also allowed the damage to be graded for severity to focus the study on the key areas required more urgent attention and energies. An example of one of these devised damage templates is shown below in Figure 22. The remaining templates can be viewed in the annex of this thesis. Since this thesis is focused on the moisture problems encountered by Barryscourt, this was the guiding point of investigation; how is the castle affected by moisture and what effect is this moisture having on the structure and its materials, where is the source for this infiltration and what are the mechanisms generating the phenomenon. By staging the examination in different levels of detail the problem is broken-down into layers which can allow more rigorous scrutiny and understanding.

Barryscourt Tower House - Interior		PH_03
DAMAGE	Moisture induced staining and surface deterioration	Grading: Moderate
LOCATION	Global problem occurring on most interior walls of the tower house, especially noticeable in first floor hall, Great Chamber hall walls, northeast tower rooms exhibit many staining patches.	
CAUSES	Moisture causing staining - Number of contribution factors including faulty roof sealing joints, inadequate drainage. However, the moisture staining patches also occur in the middle of walls signifying porous masonry which is facilitating the ingress of moisture in times of rain and accelerating when accompanied by driving wind.	
MAIN MECHANISM	Water works through wall by differential pressure force and infiltrates to interior facades where it stays, causing staining of materials, namely lime wash and mortar joints, stone facing and timber. Constant moisture causes limewash to discolour to cream/yellow. Water combines with tannins in timber and stains walls when dripping or pouring. Water leaves staining lines and watermarks on naked stone.	
INTERVENTION PLAN	Roof sections should be repaired/ maintained. (See last template for intervention). Walls of castle should be repointed to repair mortar joints which are allowing moisture through. Rendering external plaster should be ideally reapplied using lime render to improve waterproofing whilst still allowing the walls to breathe in times of dry weather. Ventilation should be maximised to aerate the building during these times also and further the drying process.	

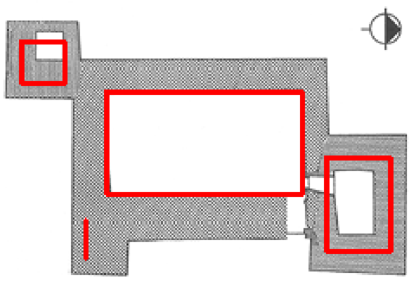


Figure 22: An example of the formulated damage templates – Physical damage (weathering)

4.1 Preliminary Site Investigation/Inspection

The preliminary site investigation was carried out on the 21st of April, 2011. The external air temperature was recorded as 17^o C and the external relative humidity was 69%.

4.1.1 Exterior of Castle

Externally, overall the building appears to be in very good condition indeed, wholly intact with no collapsed sections, ruptured masonry and unharmed ramparts. However, upon closer inspection, the building has minor problems such as continued pockets of lodged vegetation which is rooting in cracks in the joint mortar and between the mortar itself and the surrounding stones. These plants are causing clumps of mortar to detach from the joints and when these plants are removed they leave gaping holes to allow more water to be driven further into the masonry (Figure 23).

Figure 23: (a) Vegetation on external castle wall (b) Associated mortar deterioration

The overhanging dripstones which act as overflow spouts for the rooftop rainwater seem to be working for their original intended purpose however noticeable staining occurs down the castle façade from the trailing drained water. This staining is quite prominent on all facades below the dripstones but also on the batter section of the wall (Figure 24). This black staining seems to be due to mould and lichen formation, named the lichen *Placynthium nigrum* (Seawright, 2009). This lichen is widespread throughout Ireland, developing on slow-drying calcareous rocks and old mortar such as found at Barryscourt. Similarly, some patches of white lichens can be found near the black lichens, and see to be of the *Verrucariaceae* lichen species, perhaps, *Verrucaria hochstetteri*. This lichen also commonly occurs on Irish limestone throughout the country and can cause damage such as pock marks if left for long periods of time.

(a) (b)


Figure 24: Black staining under dripstones and on batter – (a) North face (b) East face

The mortar loss situation is not associated solely where vegetation has gained hold but also occurs on the lower section of the wall; especially on the batter (the widened base section of the defensive external wall – widened for stability and to deter undermining and also to deflect objects dropped from the ramparts onto attackers). Significant sections of the mortar have fallen away from between the stones, leaving large openings vulnerable to moisture and plant life. The most affected region is on the western batter wall which also receives the majority of wind and rain due to the prevailing wind direction being from this side (see Figure 11). It was quite sandy to the touch and detached in pieces when rubbed with ones fingers indicating the poor binding strength of the mortar itself. The more exposed the joint had been made to the elements from exfoliation and spalling, the worse the mortar condition (Figure 25).

Figure 25: Stone and mortar deterioration on lower sections of wall (batter) - West façade

4.1.2 Interior of Castle

Ground Floor:

Once inside the main castle entrance the first noticeable aspect of the internal environment is the abundant humidity in the air. The flooring flagstones were visibly damp and showed dark marks especially near the joints indicating the abundance of moisture in the flooring (see Figure 26a). This dampness was more evident and extensive near the edges of the room where the base of the walls meet the internal flooring.

(a)  (b) 

Figure 26: (a) Ground floor dampness and staining on flagstones; (b) Overhead timber flooring

All walls exhibited dampness and moisture was visible on the faces of the walls with large scale overall staining of the lime wash coated interior. Areas which had been subjected to long periods of prevailing moisture had become discoloured (cream/yellow) and were in poor condition (flaking, spalling and hollow sounding when lightly hammered). This staining was extensive on all walls. Where some of the overbearing beams and support joists were in contact with the masonry (particularly on the west side below the upstairs fireplace), staining was apparent (see Figure 26b) and the timber was damp to touch. Similar to the overhanging roof beams/joists, the legs of the timber display-boards/stands which are located around the room for visitors all exhibit staining from absorbing moisture from the damp floors via capillary action. The small dungeon was difficult to examine due to the dim lighting for atmospheric display purposes but when examined closely exhibited similar damp conditions as the main room to which is it now adjoined.

First Floor:

The condition of the first floor is quite similar to that of the ground floor. The lime washed walls and vaulted ceiling exhibited large scale staining; the west wall had the most extensive staining and this was particularly obvious around the flue section that rises straight up from the fireplace (see Figure 27a). This flue had large yellow/cream staining from moisture.

(a)  (b) 

Figure 27: (a) Extensive cream/yellow staining near the chimney in the first floor; (b) Poor mortar condition/biological activity in the first floor room of the southeast turret

Throughout the whole room the lime wash was detaching in many regions and mortar from some the underlying joints was in the early stages of detachment. The walls in and around the window recesses appeared shiny when seen from afar, and upon closer inspection the walls in these sections were found to be wet. The large garderobe off the hall and the kitchen both also exhibited this moisture. It was only very apparent near the window, where certain sections were illuminated the outside light, but all walls were damp and cold to the touch. Close to the present window panes, areas of the inside walls had green moss and biological activity thriving in the moisture ridden surroundings – this was most evident inside the windows of the south-eastern turret room of this floor (see Figure 27b). Some sections of this room also had visible efflorescence with salt build up on exposed stones.

Most of the windows possess the ventilation opening in their sill (as described in earlier sections) which allows significant convection of outside air to circulate through the interior chambers. This is also evident in the latrine and garderobe where the waste shoots are remain exposed within the external walls and these rooms are quite draughty, giving good ventilation. Exiting the first floor, access to the second floor (the Great Chamber) is by the main stairway along the east wall. This ascent yielded more aspects of the damp interior such as the biological growth inside the small slit windows along the stairway; green mould was growing on the steps inside all windows and it is worth noting that these slit windows are open to the exterior and are blocked against animals using steel mesh. The steps of the stairway also appear to have been repaired quite recently and the mortar of the joints appears very grey, a dark grey which is enough to provoke suspicions of large amounts of ordinary Portland cement.

Second Floor:

The Great Hall has various and clear damage throughout the whole main hall and its ancillary rooms. The large whitewashed walls are firstly noteworthy for the remaining sections of the original plaster work. Large portions of this plaster remain on the northern end of the chamber yet are too high to allow closer inspection. The floor flagstones yet again exhibited significant moisture by the darkened edges near the joints between flags. Nearer the walls and particularly around the front of the fireplace were the most affected areas. All walls show stained regions; large patches show on the west wall and the east wall with darkened spots and discolouration of the limewash (see Figure 28).

(a)  (b) 

Figure 28: Moisture staining on Great Chamber walls – (a) West wall (b) East wall

A different type of staining was found on the gable ends of the room (north and south). Here there is a different type of staining, where moisture appears to have infiltrated the timber and the resulting solution has run down the walls in times of long term rain. This staining is quite unsightly and occurs in both gables ends – the staining is brown in colour and indicates that the troublesome water is mixing with the tannin in the oak timber (see Figure 29).

Figure 29: Staining from water-oak tannin on gable walls of Great Chamber

The fireplace was another focal point for additional moisture; as mentioned, the flagstones were particularly damp here and the interior of the chimney surround was dripping with water coming from within the chimney flue. When the interior of the chimney was examined (it is large enough to walk underneath) large scale deterioration was observed with mortar loss, rampant staining and an extreme presence of moisture.

The site investigation continued down the passageway, up the spiral staircase to the master bedchamber. The chapel was bypassed due to the fact that the Office of Public Works had installed ultra violet lamps in the room which were being used to kill the biological activity (moulds and fungi) that were thriving in the moist conditions. Due to the sensitivity of the experiment and the interior paintings which the ultraviolet rays were hoping to protect, entry was denied.

Master Bed Chamber:

The master bedchamber was certainly the room in the castle which is suffering the most due to water infiltration. Upon entering the room, there was yet again a damp odour and the scale of biological activity upon the walls was alarming. All walls in the room, exhibited thriving moulds and various types of fungi. As a result of this biological presence, the walls had incurred a vibrant green surface staining which was a global issue in the room (see Figure 30).

(a) (b)

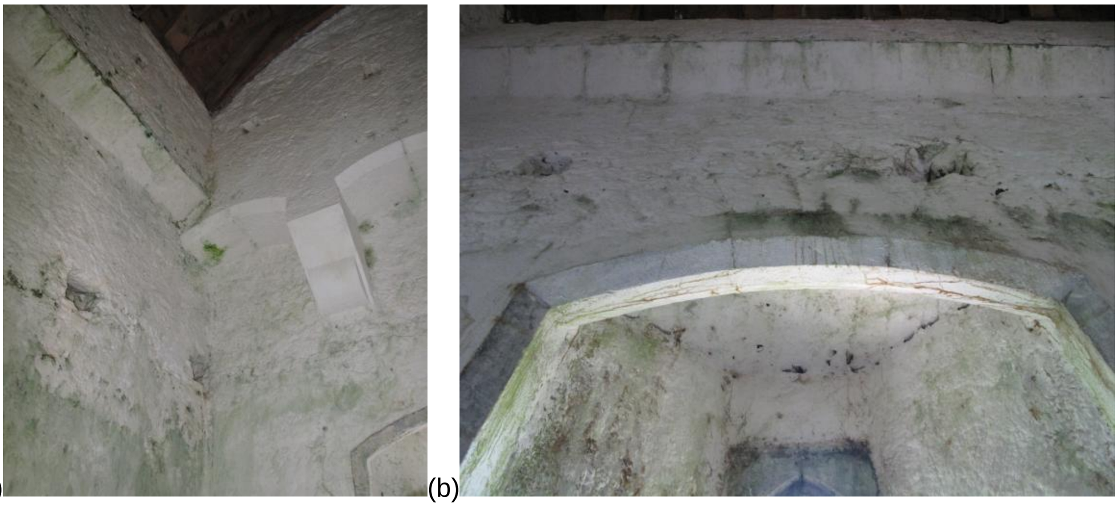
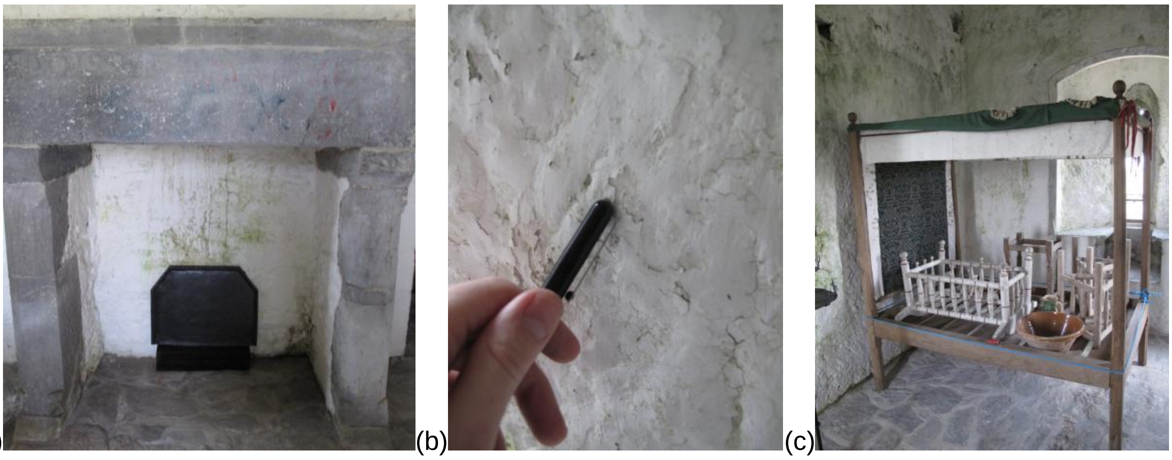


Figure 30: Thriving biological activity in the Master Bedchamber on all walls and window surroundings

Underneath the north facing window, stubborn moulds were flourishing in the noticeably damp surroundings. The chimney from the main fireplace also showed massive staining underneath the chimney flue and yet again, stained dripping water which had percolated down the chimney walls were visible from the room interior (see Figure 31a). The walls of the room were visibly suffering from the water damage, with widespread surface degradation, spalling and extensive exfoliation (see Figure 31b)



(a) (b) (c)

Figure 31: (a) Moisture staining from interior of bedroom chimney; (b) Surface exfoliation and (c) Textile removal due to damaging environment

All four corners of the room had significant staining with visible tracks of the water drips, again stained by the oak tannins. The corners of the room where the chimney walls meet the southern walls of the room also exhibited this staining and dripping. The oak timber roof structure displayed water damage in all sections but especially in the sections in close proximity to the contact points with the supporting walls. There was staining in the central points of this roof also but it is suspected to be from the storm water incurred during the construction period. The room is normally furnished with typical features of a 16th century masters bedroom including bed, baby's cot and reproduction textiles. These textiles had been removed because the room was proving to be too damp and as a result (see Figure 31c), was having an aggressive effect on the textiles, generating moulds and fungi spots. The adjoining latrine was suffering from similar moisture problems and the mortar/lime washed masonry wall was visibly in poor condition. The oak seat of the toilet was permanently stained due to the presence of water also.

4.1.3 Primary Visual Inspection Discussion

This site visit was during late April of 2011, and it is noteworthy that the weather had been largely dry (by Irish standards) for a few weeks prior to the visit, thus the building was allowed some time to dry out. The caretaker at Barryscourt made the author aware that the building was in far worse condition during the winter months. Water was infiltrating at an alarming rate, visibly percolating down walls, dripping from chimneys in all rooms, there was a steady trickle of water down the spiral staircase which had to be evacuated using a sweeping brush. So, even though the castle was visibly suffering during this visit, it was far from the worst. Barryscourt possesses a serious problem with water ingress and it is certainly having detrimental effects on the structure, with global mortar damage, surface exfoliation, extensive presence of moulds and fungi – namely wreaking havoc in the chapel as noted by the need for ultra violet lamps, timber staining and textile damage. Luckily, the walls have been whitewashed, which made identifying moisture pockets easier due to the discolouration they incur in the presence of water.

The ground floor showed large amounts of moisture especially around the edgings where the floor meets the main walls. This indicates that the moisture is originating from the surrounding walls and more probably from rising damp in these lower wall sections, wicking moisture from the ground soil. The timbered ceiling of this room was experiencing staining especially around the fireplace of the room above further illustrating that a problem in one section has a knock on effect to surrounding features and components of the structure. The first floor has more apparent wall staining from moisture intrusion, with large sections of darkened and discoloured limewash especially around the chimney flue. The most affected room at this associated level was in the south-eastern turret which displayed significant biological activity near the windows and wall efflorescence.

The second floor also suffers from global staining, both on the wall faces and of the surface limewashes but also on the gable ends of the room where water is mixing with the timber tannins and rolling down the wall surface. The staining is not localised in the corner points of the room but rather occurs all across the gable ends. The stain pattern is so spread out that it indicates more that the infiltrating moisture which is migrating through the walls is reaching the timber structure, mixing with the oak tannins and trickling down the surface, rather than occurring solely from a roof leak. Again, major infiltration is occurring through the chimney as more moisture was evident surrounding this region.

The Master bedroom was undoubtedly the most affected/damaged room of the whole building and its situation is quite serious. As observed, biological activity is rampant due to the ideal conditions for such vegetation and fungi, wreaking havoc on the wall surfaces, the timber structure and the furnishings. At this point it is uncertain whether the roof is leaking in the corners where the staining is occurring, or if it is moisture from the walls moving through the oak and staining the walls as a result. Further examination will be more conclusive and required to give an accurate assessment. Although this survey did not include a visit to the chapel, it is apparently suffering from similar conditions as the bedchamber, and the need for ultra violet lighting to fend off biological activity highlights the current buildings condition and its problems with moisture.

Externally the building appears solid and sturdy with no noticeable cracking or out of plane movement. Settlement does not appear to be an issue on any side of the building and apart from pockets of vegetation and staining the exteriors main problem is mortar loss, with particular significance on the western façade. It is not just coincidental that this façade also receives the majority of the rain and wind (see prevailing wind and rain directions: Figure 11). This strongly indicates the effect of the driving wind and rain and the damage this side incurs due to the buildings orientation. The master bedchamber also receives the brunt of the elements from the same direction as it juts out from the castle on the northern end as part of the north-eastern turret.

Due to the many openings throughout the castle there is no shortage of ventilation in Barryscourt. The garderobes adjoined to the main halls have open shafts which run down the walls to cesspit exit holes on the lower levels. The drain spouts under the window frames which were originally intended for water drainage and ventilation, now act as ventilation gaps allowing air to circulate around the window surrounds. Some of the slit windows (arrow loops) in the castle have no covering glass and air is felt circulating through all spiral staircases (see Figure 32a). The master bedchamber has air circulating through the room at all times from the outside spiral staircase and the exit shoot of the adjoined latrine. The more ornate windows such as the mullioned window frame of the master bedchamber also has the benefit of an opening section of the window frame to allow extra air circulate through the room.

Additionally, the chimney has a capping stone which is not sealed at the top, allowing more air to move through the chimney shaft (see Figure 32b). In fact, many of the windows at Barryscourt, apart from the ground floor windows, possess the drainage outlets or opening frame sections which work in unison with the open chimney flues, waste exit shoots from latrines (see Figure 32c), arrow loops and door gaps, to allow fluent transportation of air through the building. With ample air flow, it is safe to say that Barryscourt does not have an issue with ventilation in the interior environment.

(a)  (b)  (c) 

Figure 32: Examples of the abundant openings throughout Barryscourt which contribute to ventilation (a) Waste shoot from main garderobe of Great Hall (b) Open arrow loops of main staircase (c) Unsealed chimney capping

4.2 Non Destructive Testing – Thermography Testing

After the initial site investigation, it was evident that Barryscourt has a serious problem regarding moisture infiltration and the damage associated with this ingression. Further methods were needed to fully strengthen this observation, to identify key areas of intrusion and to possibly point out the most seriously affected regions giving clues to how an intervention may combat this problem. There are various different methods for analysing a structure, its components and affecting issues and this thesis study was fortunate enough to benefit from a non-destructive thermovision analysis of the structure, and the guidance of a visiting Professor from the University of Minho's civil department.

Assessing the presence of moisture in a structures wall, ceiling and roof is just one of the multiple uses of thermal imaging, or infrared thermography. The thermal imaging camera detects radiation from an examined surface, and produces images of the detected radiation in a thermo image known as a thermogram. Since all surfaces/objects emit infrared radiation, and the amount of radiation emitted increases with temperature, the thermography shows regions of different temperature and allows one to differentiate between hidden objects, materials and substances. Water may have infiltrated the castle through a number of ways such as by capillary action from the lower sections of the wall, seepage through the porous wall via the pressure differential during high winds and rain, through cracks not easily visible to the naked eye or through roof openings and leaks. Shortly after rain, water can infiltrate via one of these mechanisms and invade the buildings interiors. When such a situation arises, the camera can detect the lower temperature of the moisture by reading and projecting the various surface temperatures of the wall/roof section exposing regions of lower temperature. The reason for a skilled operator and interpreter of the camera is critical however; since the camera only detects surface temperature it can be difficult to interpret the resulting reading such as in the case where different materials or underlying foreign objects/ voids are present. The camera will show a differential colour in these positions and these must not be confused with the presence of moisture.

4.2.1 Thermo Camera Trial Runs

The thermography analysis was conducted using a handheld point and shoot ThermaCAM T400 used in conjunction with Flier Systems. Several tests were carried out and are summarised as follows:

Guimarães Castle:

The camera's effectiveness was first assessed by visiting castle Guimarães in Portugal, located near the University of Minho to see how the camera behaved whilst analysing thick walls, such as the ones which would be assessed in Barryscourt. The temperatures inside and outside the castle were similar and therefore only some small regions showed any sort of moisture due to the matching climatic conditions. Additionally, the weather prior to the test had been very dry and sunny. If there is one thing that can be guaranteed in Ireland, it is rain.

Barryscourt Castle - Test 1 (15th/June/2011):

The test went ahead in Barryscourt castle in Ireland on the 15th/June/2011 and the rain which had been relied upon fell just as predicted. However, the camera did not show up much of the moisture in the castle interior. The resulting images were unclear and the temperature differential in the walls was so uniform that the moisture was mostly undetectable. This setback was solved by changing the emissivity setting in accordance with the characteristics of the wall and by adjusting the temperature and humidity values in accordance with the values found on site.

During this testing, the castle walls were observed to have a large amount of salts evident on the interior walls – particularly in the ground floor and the first floor, and inside the windows of these floors (see Figure 33a). They appear as a white “fur” attached to the walls and were not so evident during the primary visual inspection.

It is important to note that the castle was in a drier condition than when it was first examined over 6 weeks earlier. The castle had dried out during this break from the winter rainfall and the salts which had been present in the building at the time, but in a soluble state, became crystallised on the wall surfaces as the building dried out, hence becoming much more visible and apparent during the second visit. As the walls dry out, the internal moisture migrates to the wall surface and evaporates to the atmosphere. Through this migration, the moisture carries the internal salts and deposits them on the walls surface. During the primary inspection, the surface of these walls in these identical locations was wet due to condensation (see Figure 33b & Figure 33c). The salts may have been staying soluble and undetectable under the abundant condensation on the walls during the first site visit. Once the building and the climate had improved, the salts recrystallize and appear as the white fur on the surface.

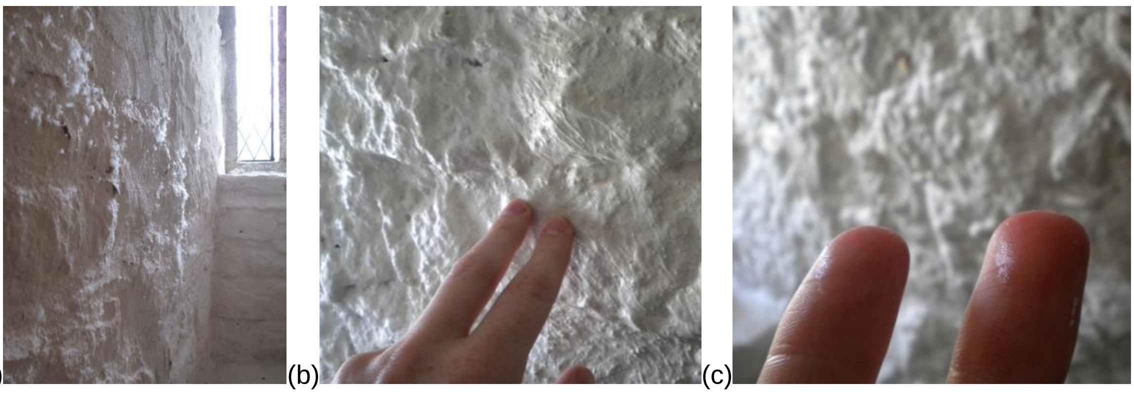

(a) (b) (c)

Figure 33: (a) Salt crystals appearing as white “fur” which were clearly visible upon the secondary site inspection whereas (b) & (c) Photos during primary site inspection of identical window with condensation on walls

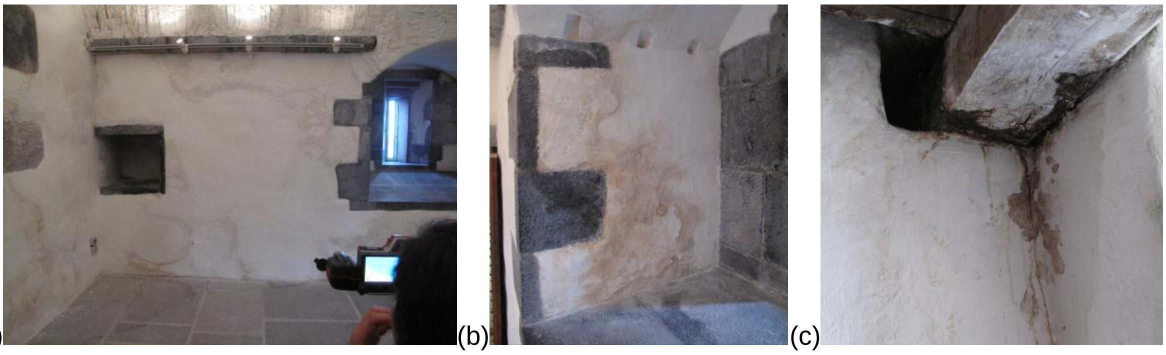
Ross Castle Test (16th/June/2011):

On the following day, using the altered camera settings, an additional thermography analysis was conducted on another Irish tower house in Killarney, County Kerry in Ireland (Figure 34). This 15th century castle, named Ross Castle, exhibits almost identical problems to Barryscourt due to major water infiltration, and is arguably in a worse condition as a result of this ingression. This tower house is smaller than Barryscourt but is another fine example of such a construction residing adjacent to Loch Leane, one of the famous Lakes of Killarney of the Kerry National Park, in a water abundant location, at the foot of the Killarney Mountains. County Kerry receives higher average rainfall levels than County Cork, further adding to the castles moisture problems. Ross castle also possesses underfloor heating in the castles main block floors, which when turned on, draws the moisture into the building and causes even more noticeable and harmful damage to the interior materials. The thermography testing analysis of Ross castle was conducted while the underfloor heating was turned on.

(a)  (b) 

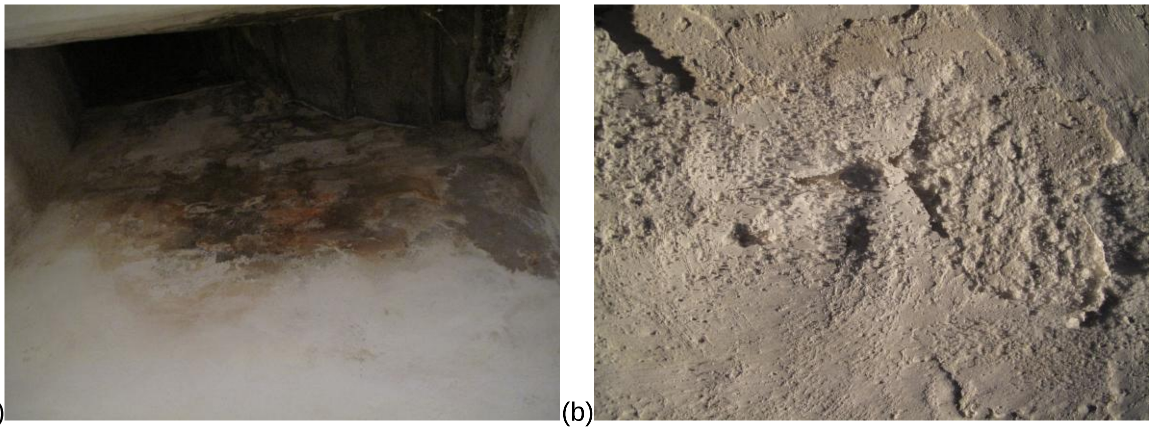
Figure 34: Ross Castle, Killarney, County Kerry, Ireland; (a) West face (b) South face

Various moisture-influenced damage evident in the castle include staining, rising damp, material deterioration, mortar loss, salt damage, material spalling, exfoliation and deteriorating timber structural elements (see Figure 35). Mould and fungus were running rife in the building also and just like Barryscourt, were affecting textiles and furnishings. Areas which could not be tended to by limewashing showed even worse damage, such as the chimney interior (see Figure 36a). The resulting thermography images are found and discussed in the following in section 5.1.1 of the results chapter.



(a) (b) (c)

Figure 35: (a) Moisture damage/staining in ground floor of Ross Castle; (b) Significant problems near window openings; (c) Decay of structural timber due to moisture presence



(a) (b)

Figure 36: (a) Moisture damage in interior of Ross Castle chimney; (b) Abundance of salts and the associated material damage/exfoliation

4.2.2 Barryscourt Castle Main Thermography Analysis:

The analysis at Ross Castle was more successful due to the buildings underfloor heating. An additional test was conducted on Barryscourt on the same day. It had rained since the previous examination, the temperature was recorded as 11^{o} Celsius and the internal relative humidity was 85.4%, so conditions were more favourable. The testing was carried out in exactly the same way as the Ross castle analysis, with the updated emissivity and humidity settings. All rooms of all floors were re-examined and on this occasion the analysis was far more sensitive and illustrative of the moisture presence. Each section of damage which was observed and recorded in the preliminary visual inspection was tested using the camera. The thermography findings generated suspicions about the roof performance in some rooms, particularly in the master bedchamber. This provoked the need for a further rooftop/wall-walk inspection, which is outlined in the next section 4.3. A selection of the most important resulting images and their corresponding discussion of the findings are found in section 5.1.2 of the following results chapter.

Figure 37: Thermography analysis of Barryscourt tower house using handheld ThemaCAM T400 camera

4.3 Roof Survey

After firmly establishing that there was a problem originating from the roof in the master bedchamber, the Office of Public Works were contacted and made aware of the problem. An inspection of the roof was organised with the head foreman from the headquarters of the Office of Public Works in Charlesfort in Kinsale, Cork. The foreman, a qualified carpenter by trade, actually worked on the construction of the oak timber frame roof of Barryscourt during the restoration project. His knowledge of the construction stages and design detail was invaluable, as he described the manner in which the lead flashing, felt and slate were arranged and attached. The roof of Barryscourt (see Figure 38) is accessible by the spiral staircases of the corner turrets, is not open to the public and is rarely visited even the caretaker.

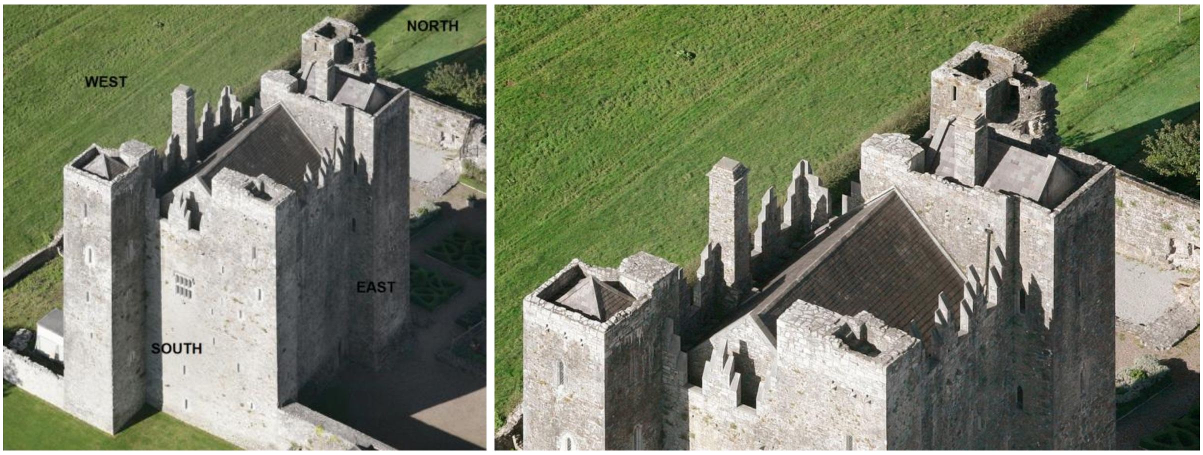


Figure 38: Aerial photo of Barryscourt Castle from southeast (OPW Archives, 2011)

The roof surface consists of slate with underlying felt nailed to the roof battens, with a slight bell cast shape (curved section of lower pitch at the bottom of the roof surface used to slow flowing rain water), with the crest of the roof mounted with a limestone copestone (see Figure 39). During the primary inspection of the roof underside, the timber beams appeared stained and leaks were suspected. This staining however was as a result of rain water which fell on the timber structure during its construction phase during a storm. The protecting plastic was blown off and the oak timber was stained and remains to this day.

The original system for draining the roof rain water was almost completely restored to its original design. The original design has a series of runoff stones called “waterstones” which lie along the wall walk. Similar rounded saddle stones cap the joints between each waterstone. This design operates with rain water running off the roof surface, down onto the waterstones (which have a slight inclination) and then the water runs out through a series of spouts called dripstones which are positioned at approximate intervals of 2 metres.

Today, this system is still in place on both the northeast and southwest turrets, whereas an additional single cast iron gutter runs the length of the roof ending on the east and west sides of the main roof. This gutter is positioned to catch runoff water and the accumulated water is then discharged via differently positioned downspouts which were built into the wall during the restoration project.

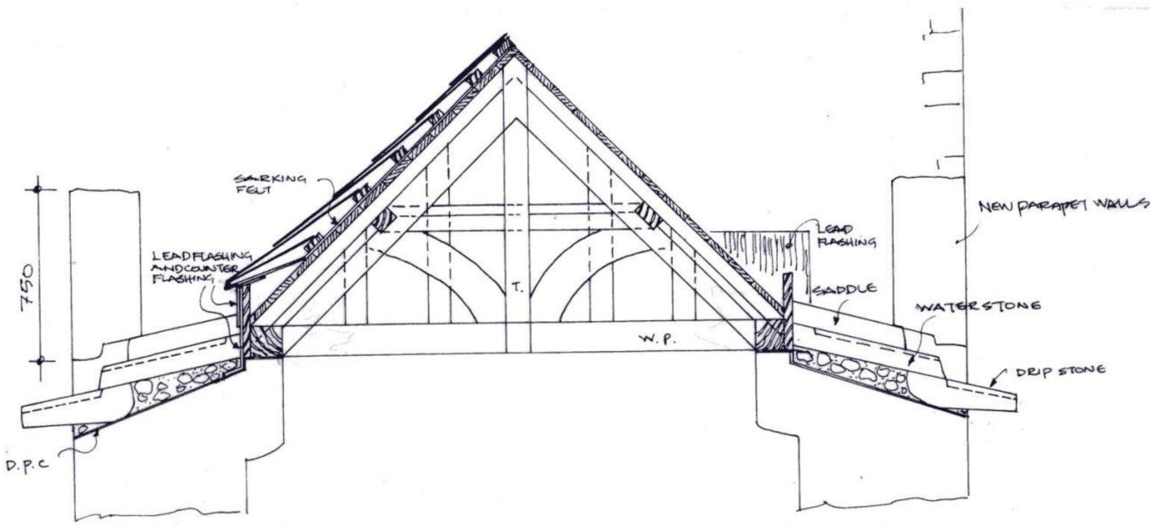


Figure 39: Roof restoration drawing illustrating roof & drainage components – (Stapleton, 1999)

Barryscourt roof is accessed through different small entrances and the wall walk regions are interrupted allowing only one section to be examined at one time. Therefore, the inspection was split into four main parts (see Figure 40). The roof inspection was carried out on the 27th of June, 2011.

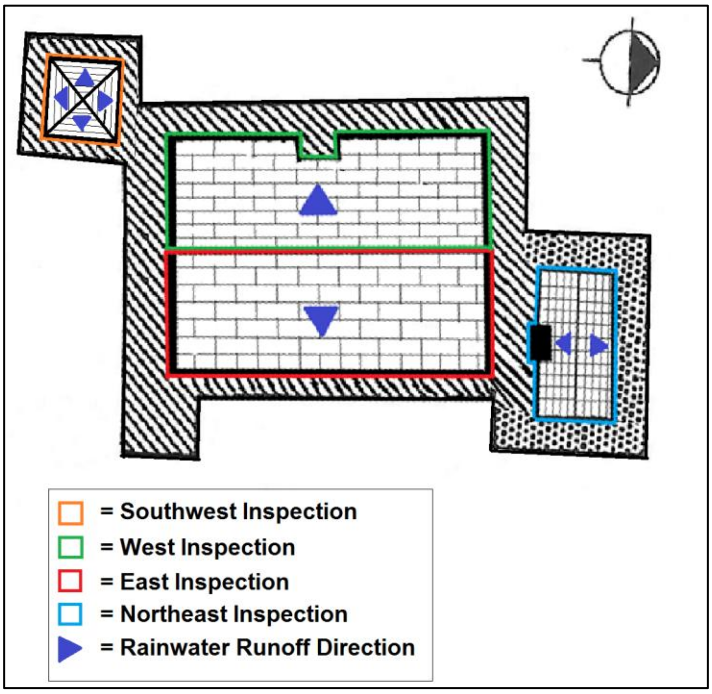


Figure 40: Plan of Barryscourt: Inspection sections – Adjusted sketch from (Monk & Tobin, 1991)

4.3.1 East Section

The first area of the roof inspected was the east side of the main roof (see Figure 40). Accessed via the northeast turret spiral staircase, there is an uninterrupted wall walk on this side. The first observation made was the abundance of vegetation and organic debris at this level. Plants, weeds, bird nests and mosses are dotted along the drainage line which can cause obstruction to flow paths, slowing the evacuation of rainwater. When some plants were removed it was clear that the roots had penetrated into the surrounding mortar and lead flashing causing small openings and inlets for water. The drainage gutter was littered with organic debris and the whole wall walk appeared to be untended.

Figure 41: East roof surface and waterstone drainage arrangement

The roof surface appears to be in good condition, with no observed broken slates or displaced courses. Under the first course of slate (moving from bottom to top) lies a thick blanket of lead flashing which runs down and under the waterstones and saddle stones (see Figure 42). This lead is overlapped and counter flashed with well moulded joints and appears to be in good condition. The waterstones are arranged alongside each other with a capping “saddle” stone which overlies the joint of the two waterstones. These are joined using more of the restoration mortar. The cast iron gutter is held up by cast iron support brackets which are screwed in through the lead flashing into the underlying support structure. The saddle stones do not appear to be sealed very well and the quality of the bonding mortar is in very poor condition in multiple regions, which can allow moisture to penetrate quite easily. The gutter size and position is also questionable since the roof has such a steeply pitched angle and the catch gutter sits well under the eave of the final course of slates. In times of heavy rain, the momentum of the rainfall runoff would appear to be so great as to even overshoot the gutter and land on the waterstones.

The waterstones themselves have only a slight inclination towards the outlet dripstones, a slope so small that water must take quite a while to evacuate the surface, time enough to soak into the surrounding mortar and in the presence of high winds, work its way under the stones and lead flashing. Their surface is also very flat, so the evacuating water is not channelled away from the edges but can rather flow over the whole surface. The outlets along the wall walk, where the dripstones are located, funnel significant air flow when the wind blows against the building and this convection would seem to drive additional water back towards the building if the wind blows against the direction of the outlet, slowing water evacuation and pushing the water back towards the building.

(a)  (b) 

Figure 42: Close up views of drainage gutter, lead flashing and counter flashing, waterstones and capping saddle stones

4.3.2 Northeast Turret Roof

Also accessed via the spiral staircase, north-eastern turret has a similar designed roof to the main building, and is gabled at the east and west (see Figure 40). The south side of the roof is built around the chimney stack which stems from the master bedchamber down below. This room exhibited staining at the corners where the roof meets the chimney stack, and the thermography analysis showed up moisture at these meeting points also, so this roof was closely scrutinised.

The roof drainage system allows the water to run off the roof surface, onto the water stones and evacuates out the dripstones which are positioned equidistant on all sides. There is no gutter, located under the eaves, as was found on the east roof of the main building. Vegetation is rife in most corners and just like what was found previously, roots have worked their way into the corner joints, mortar and lead flashing (see Figure 43a). The roots and stems of these plants have pushed out mortar and have caused some large openings to the inner joints between the roof and the walls, openings through which moisture could easily infiltrate (see Figure 43b). The mortar around the joints, waterstones and saddles was found to be damp, earth and organic debris are found in gaps and surfaces and this too was moisture laden. The lead flashing on the south and north sections of this roof was as found to be of identical design to the main roof. At the foot of the gabled ends, a single leaf lead curtain was the waterproofing feature, secured into the mortar of the gabled ends plastered surface, (one of the few plastered sections of the castle). This lead curtain then slopes down against the face of the gable end to allow water to run down the face of the plaster and move away from the base of the wall and out onto the waterstones and away (see Figure 44a). This lead curtain however was quite loose and when the underlying region was examined, the mortar underneath was found to be damp with lots of small plants and varied vegetation rooted. The lead did not finish flush with the wall walk surface and a significant gap allows the underneath areas to be exposed to the elements, more concerning in times of driving wind and rain.

(a) (b)


Figure 43: (a) Vegetation rooted in corners; (b) Mortar damage and openings due to vegetation growth

In some edgings of the roof, the lead flashing had been sealed to the wall using silicone. This silicone had deteriorated since the restoration and allowed the flashing to separate from the wall exposing underlying regions (see Figure 44b). The corner as shown below in Figure 45 corresponds to the north-eastern corner of the bedchamber, which displayed staining from water intrusion. The south-western corner was suffering due to the exact same silicone use problems.

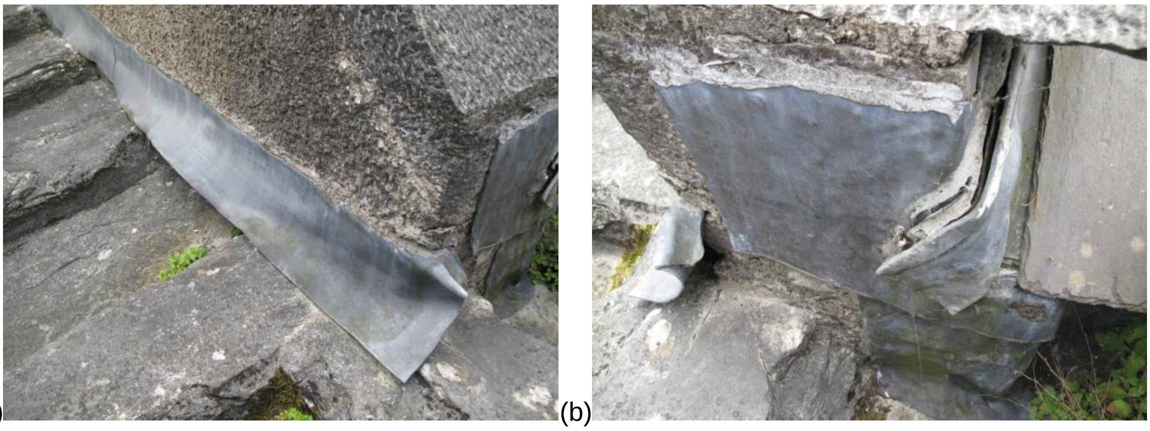
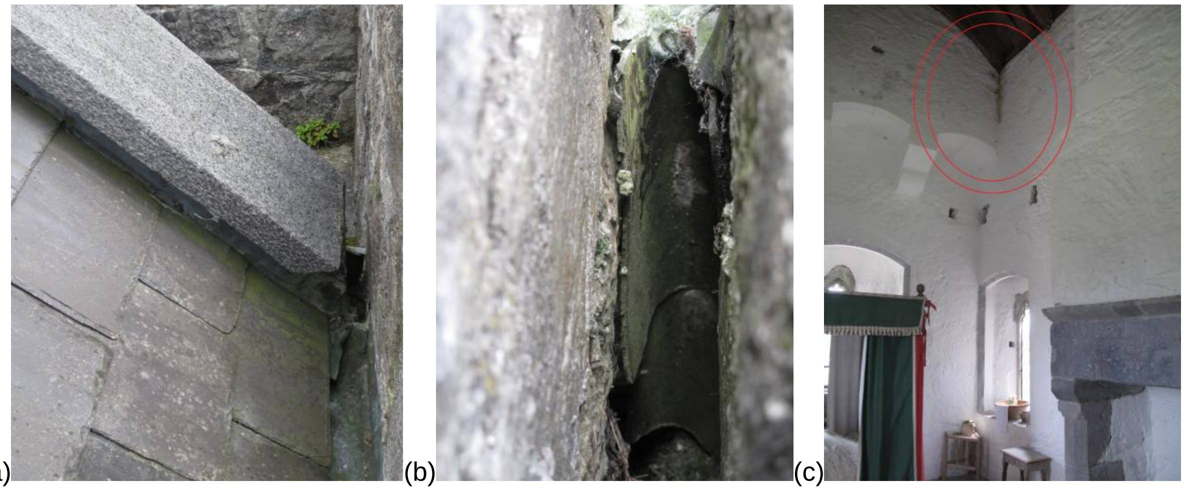
(a) (b)


Figure 44: (a) Lead runoff "curtain" at gable ends; (b) Inadequate flashing seals with large openings

At the base of the sloped gabled ending, the south-eastern corner of the turret had an unusual section which was entirely exposed to the elements, without any sort of lead covering but rather a few vertical overlapping pieces of old roof felt. This corner also corresponds to a leaking corner of the bedchamber, at the south-eastern corner which exhibited staining and moisture from the thermography analysis.



(a) (b) (c)

Figure 45: (a) South-eastern corner of north-eastern tower; (b) Hole in covering; (c) The corresponding infiltration in the bedchamber

On the south side of the roof, a piece of pipe, was left lying on the wall walk section, of no use whatsoever to the roof drainage. Its original intended purpose was unknown and it further highlighted the roof drainage inadequacies and lack of maintenance and general attention. Again, lots of vegetation was growing in the corners and flashing.

The section of the roof where the chimney intersects the roof surface appeared to be in good condition with little to see in the way of damaged flashing or the use of silicone. The only clues to the water infiltration at the corresponding points in the bedchamber would be due to the large plants and weeds which had lodged in the corners, and the underlying earthen debris was damp to the touch. The chimney itself had a limestone capping stone fitted to the very top of the chimney stack to deter water from entering directly. This capping stone is not sealed around the edges and water can easily intrude from all sides and down inside the chimney channel. This was also evident when the chimney interior was viewed from inside the master bedchamber.

The masonry roof over the access spiral staircase of the turret had huge sections of lime leaching all over the masonry surface. This was another section which was reconstructed during the restoration project. There were some horizontal cracks across the whole rectangular masonry section through this leached lime surface. The only source of this phenomenon is the restoration mortar since the leaching was occurring at the very top of the section where the reconstruction had been done and was moving down the surface of the wall in the presence of moisture.

4.3.3 West Section:

The west section of the main roof was the next area to be inspected (refer to Figure 40). Since the prevailing wind originates from this direction, this roof bears the brunt of the climatic conditions. The west side is almost identical to the east side of the main roof, it differs only in the way that it is interrupted by the main chimney stack which rises up through the centre of the west roof (see Figure 46a) and the way in which the gutter is drained on either by a cast iron downpipe which was built into the wall during the restoration project. These downpipes run the length of the wall and turn out when they reach the ground, projecting metres away from the castle to evacuate rainwater (see Figure 46b).

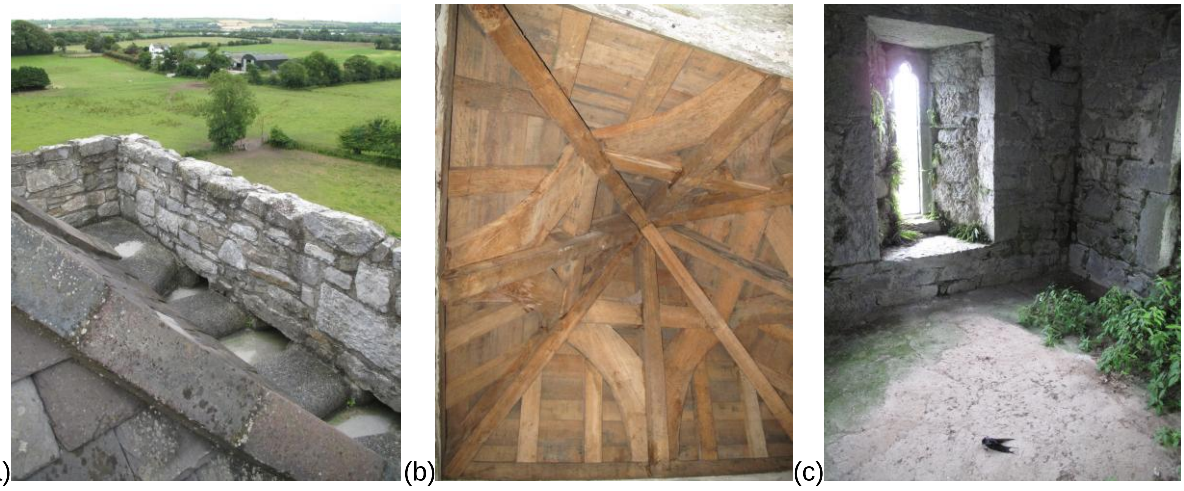
Figure 46: (a) West side of main roof with main chimney stack (b) Drainage channel with inbuilt downpipes on either side of the chimney

Figure 47: Capped/sealed main chimney and capped/unsealed bedroom chimney

On this side, the flashing appears to be in good condition, as is the roof surface with no broken slates or obvious damages. Damage is very similar to what was observed on the east side, vegetation appears to be the most problematic agent on this side with plants and weeds in abundance and associated mortar loss and damp mortar. The gutter, just like the eastern gutter, is set well in under the eaves of the roof but has the benefit of the two draining downpipes. There is no such downpipe visible on the eastern roof section. The chimney is capped with a limestone flagstone just like the chimney on the northeast turret; however the capping stone on the west side chimney is apparently sealed around the edges with mortar, unlike the northeast chimney (see Figure 47). Even though the chimney is sealed with mortar, as observed during the primary site inspection, the interior of the chimney stack had incurred serious damage from moisture infiltration, and since the top is sealed, it illustrates that that water is infiltration through the masonry.

4.3.4 Southwest Turret Roof:

Accessed through a small door at the top of the spiral staircase in the south-western turret (refer to Figure 40), it opens out onto a wall walk which runs around a pyramidal shaped slate roof which is built on an oak timber trussed frame (see Figure 48a). This roof was replaced during the restoration project and the surrounding water/dripstones were repaired / replaced. There is no gutter drainage system and wall rainfall runoff water runs straight onto the waterstones and vacates via the dripstone outlets which surround the turret. This roof appears to be working quite well, as the underlying timber structure was free from staining (see Figure 48b) with vegetation seeming to be the only obvious problem. The upper two rooms of this turret were not restored, limewashed or repointed during the restoration project and they are in a state of complete disrepair with massive mortar loss, peeling walls, large spalling sections and copious vegetation growth (see Figure 48c). These unrestored rooms, give a view of what the building condition is when unattended and what may have been the case in most rooms prior to the restorative project.



(a) (b) (c)

Figure 48: (a) Pyramid roof with waterstone wall walk; (b) Timber roof structure; (c) Unrestored top room of south-eastern turret

4.4 Water Absorption Testing

Barryscourt moisture issues are extensive through the entire building, as recorded during the visual inspection and the thermography analysis. Certainly, in the bedchamber, the main infiltration is through leaks in the corners, but this is not the only source of moisture. As seen from the thermography images, when the water leaks in to the masonry, it spreads out and appears to leach into the surrounding regions. This leads to suspicion about the absorption properties of the masonry of the building, and the necessity to investigate how the materials behave in the presence of moisture. Moisture pockets in the interior of the castle show that water is infiltrating through the walls, that the building is actually soaking the water from outside inwards. Limestone is a porous stone by nature and absorbs water through its capillary behaviour; however the lime mortar is the number one suspect for the infiltration due to its increased porosity and behaviour when subjected to moisture. Lime mortars conduct moisture to a greater extent than ordinary Portland cement mortars, which is just one of their advantages since this characteristic makes the structure breathable (Pavía et al., 2006). However, under long spells of wind and rain, this moisture works its way through the walls and its continued presence affects the interior materials. The aim of the following test was to examine the material of the building and how it behaves in the presence of water and how much moisture it absorbs.

It was decided to test the stone and mortar using a simple test known as the RILEM tube test, a test which is used to evaluate water absorption rates on building materials. Alternative names for the experiment include the Masonry Absorption Test (MAT) or the Low-Pressure Tube Test (RILEM Test Method 11.4, (RILEM Test N° 11.4, 1980).

The simple apparatus, the RILEM tube, is a graduated glass tube with a larger bowl-like end piece, which is attached to the material in question using putty or plasticine and is then filled with water (see Figure 49). This test measures the quantity of water absorbed into the material to which it is attached over a specific period of time. The test procedure was as follows:

- Prior to testing, a clean, dry, suitable location was chosen, free from cracks and various other sources of leaks which could distort results. The material being tested was noted.
- The tube was affixed to the surface using plasticine, which was reusable and non-staining to the underlying surface. The plasticine secures the tube to the material and ensures a waterproof seal between the tube and the test material. The tube was attached to one material at a time (i.e. either stone or mortar joint). The tube was then numbered and referenced.
- The tube was then slowly filled with water to the first graduation mark (in this case 4 mL graduation). Here the level of the water and the seal is observed and checked for leaks. When the seal was showing to be watertight, additional water was added slowly in small amounts ensuring no leaks. The tube was then filled to the zero graduation and the time was recorded.

- The level of the water is recorded at intervals of 0, 5, 10, 20, 30 and 60 minutes. If the level in the tube reached the final graduation, additional water was added - the volume added was recorded along with the time it was topped up.

The test was conducted on the exterior walls of Barryscourt, on all four façades. The materials analysed were the limestone block and the restoration lime/cement mortar (see Figure 49 and Figure 52). The test was also conducted inside the castle, on the interior walls (see Figure 51, Figure 53 and Figure 54) including limewashed stone and limewashed mortar and a section of the original plaster. Testing was conducted during a dry weather spell in late June after the building had been allowed to dry out somewhat, since testing the absorption during or after rainfall would distort any resulting measurements.

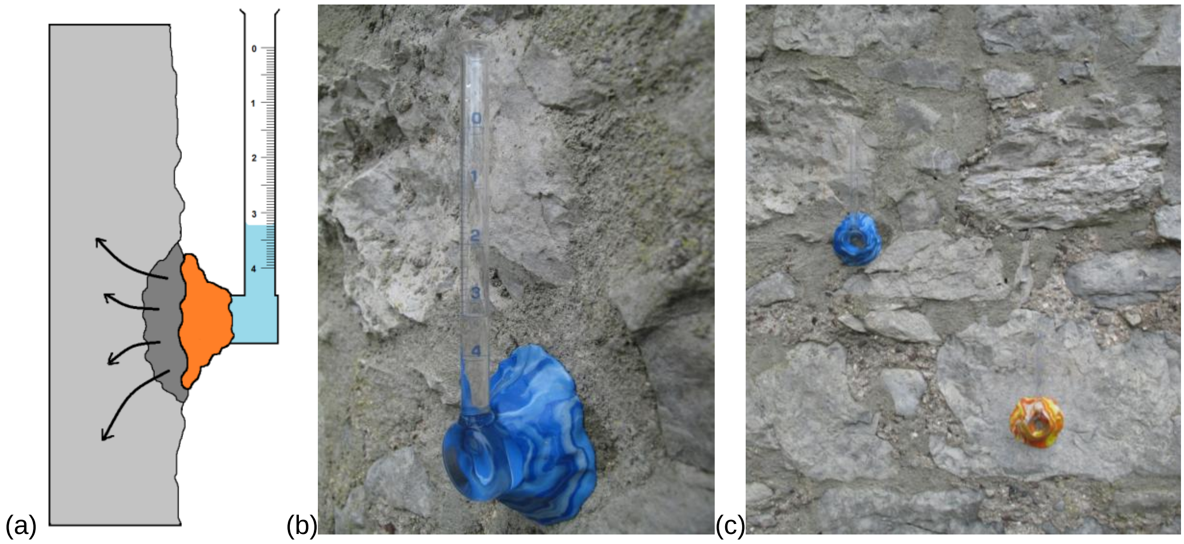


Figure 49: (a) RILEM tube test schematic; (b) Actual test set-up at Barryscourt (c) Testing of mortar and stone

As the water level decreases and the material absorbs the water, the pressure on the test surface decreases. Therefore, the pressure exerted on the surface during the test is varying, and as the water decreases and is refilled the pressure increases. The water absorption rate also increased when additional water was added. This is quite acceptable since it simulates the actual behaviour of the wind driven rain on the masonry surface i.e. driving rain is also not constant, but rather varies with gusts. This gives the experiment a realistic aspect, representing the Irish conditions during wind and rain.

The test was quite difficult to conduct in several areas due to the sandy granular surface of the mortar. Sometimes the plasticine detached from the surface, or as additional water was added to the tube, the plasticine gave way to the water and pressure increase. Also, in some areas the mortar was in considerably poor condition so it was necessary to check the mortar beforehand to determine whether there was an underlying void or whether the mortar will yield false results due to its poor condition. Solid sections of mortar and stone façades with no cracks or surface blemishes were selected. Occasionally, while the test was been conducted, the apparatus suddenly levered a portion of the mortar away from the façade (see Figure 50). This was watched very carefully in order not to cause any damage to the building during testing.

Figure 50: Easy detachment due to poor mortar quality

Whilst testing the absorption rates of the interior limewashed walls, it was observed that the area of limewash surrounding the test area became quickly discoloured due to the leaching of the test water. This continued to spread out during the duration of the test and revealed a similar pattern to those larger stain patterns observed during the visual surveys.

Figure 51: RILEM testing next to fireplace on first floor hall & water being absorbed into surrounding material (limewashed mortar)

The experimental results were recorded and graphed in order to show the different absorption rates between the stone, the external mortars, the interior limewashed stone and mortar and a section of the original interior plastering. These results can be found in the next chapter, chapter 0. The following figures (see Figure 52, Figure 53 and Figure 54) present plan views illustrating the locations of the individual water tests.

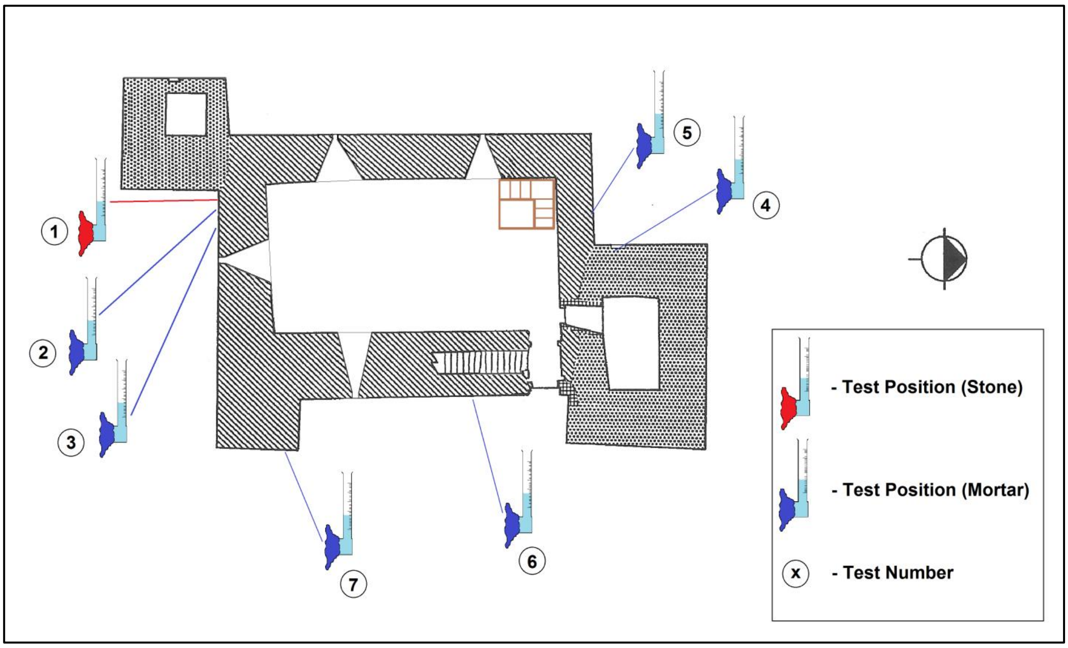


Figure 52: RILEM tube test number and positions on the exterior ground wall of Barryscourt

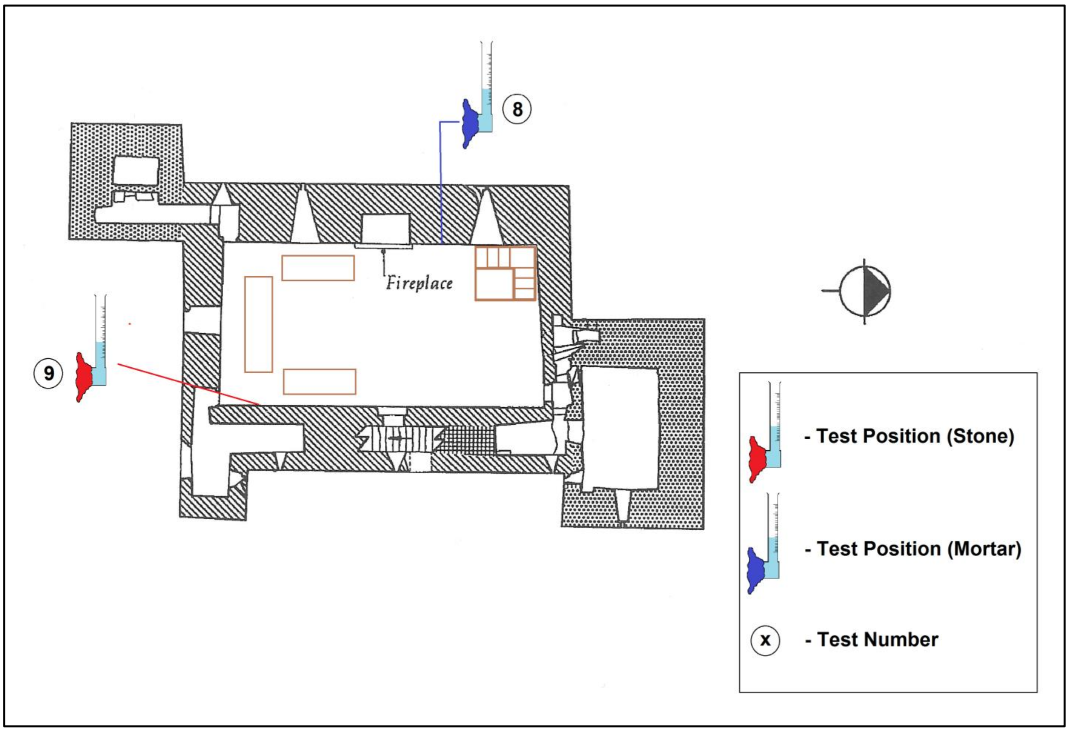


Figure 53: RILEM tube test number and positions on first floor interior wall of Barryscourt

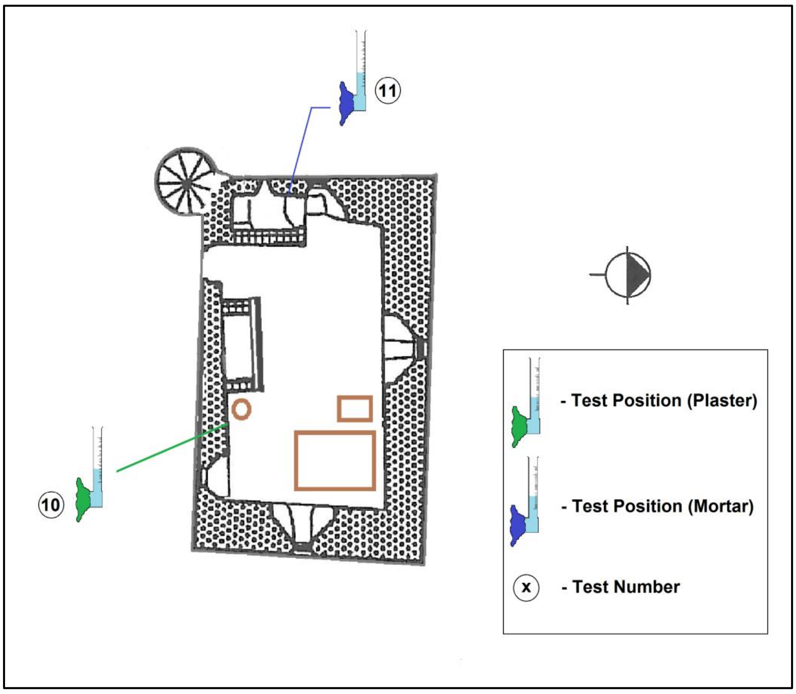


Figure 54: RILEM tube test number and positions in the Master Bedchamber interior (northeast tower)

These positional maps can be read in conjunction with the plan layout maps which appear in section 3.3.4 and the resulting graphs which appear in the results section 5.2.

4.5 Monitoring – Temperature, Humidity and Dew Point

In order to monitor the climatic conditions at Barryscourt, this study used two LASCAR electronic data-loggers (EL-USB-2-LCD) to measure the temperature, relative humidity and dew point of the interior and exterior environment. The first data-logger was placed inside the room with the most moisture damage, the Master Bedchamber and the other was placed in a sheltered point outside in the bawn wall (see Figure 55). These were both calibrated using the "*Easy Log USB"* software and were placed in position on the 28th/June/2011. They monitored the surrounding environment and logged data at hourly intervals. The data was collected for 30 days and recorded. The resulting measurements were plotted and can be seen in the following results chapter section, 5.3.

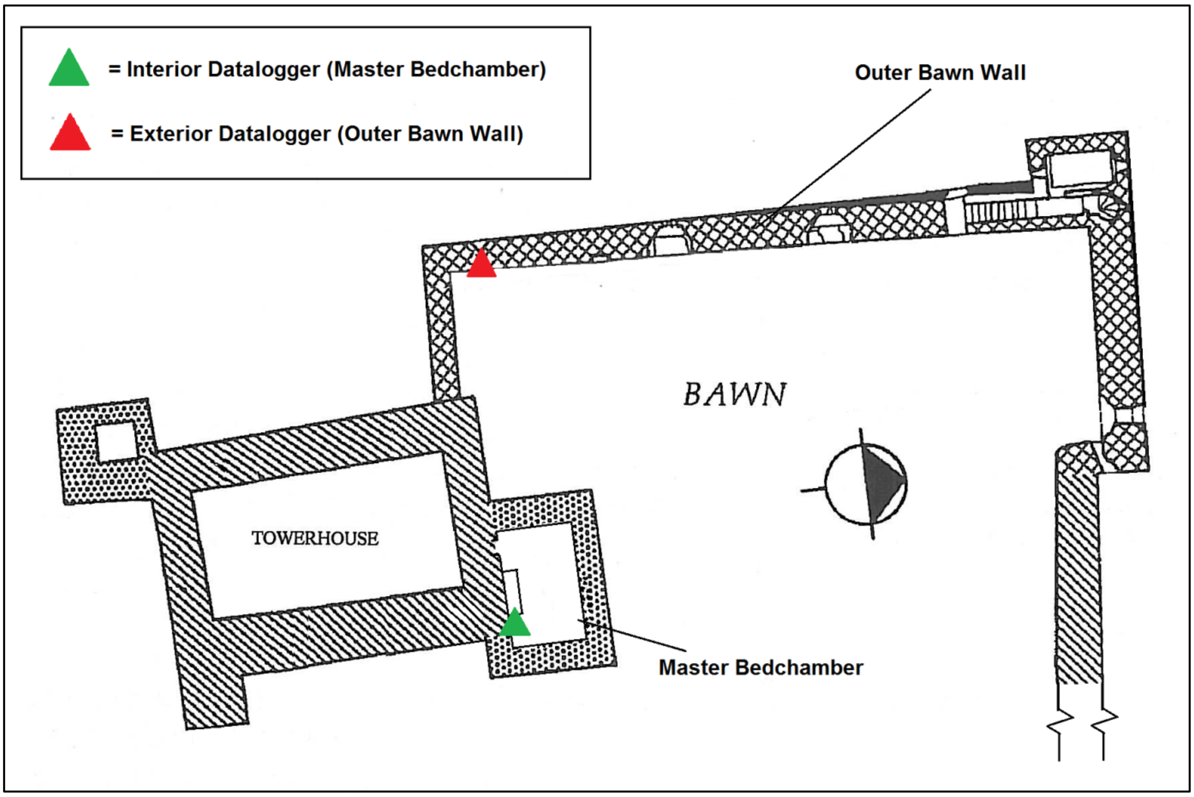


Figure 55: Positions of data-loggers during monitoring (June-July 2011)

5 TEST RESULTS

Since a significant portion of this study has been conducted through testing, the results have been grouped together to highlight the findings and give a clearer view of the moisture situation in the castle and its behaviour in response to the precipitous climate it resides in. The first set of results is from the test run in Ross Castle, as described in section 4.2.1, where the camera was tested in a similar tower house with almost identical problems to Barryscourt in Southern Ireland. Ross castle as stated earlier, has underfloor heating in place to protect interior furniture, and this was turned on during the analysis. The next set of results is from the main thermography examination at Barryscourt, which chronicles the surface temperatures of Barryscourt interior for the identification of moisture pockets and sources in the castle. The next section of results includes those acquired from the water absorption tests which were carried out on the external and internal walls of the castle on both mortar and stone. Finally, the last section presents the recorded data downloaded from the monitoring data loggers which were put in place during the water absorption testing.

5.1 Thermography Results

5.1.1 Ross Castle Thermography Results

The Ross Castle thermography analysis yielded clear thermo images of the extensive moisture in the structure. A selection of these images has been presented as follows to illustrate the extent of the damage, hidden or not. Each image has a photograph of the region being tested and the resulting thermography image from this examined section. The dotted outline drawn on each photo indicates the section which was analysed and presented in the adjacent thermography image.

The ground floor walls were extremely stained and in the following figure (Figure 56), the influencing moisture was particularly obvious in the corresponding thermography image.

(a) (b)

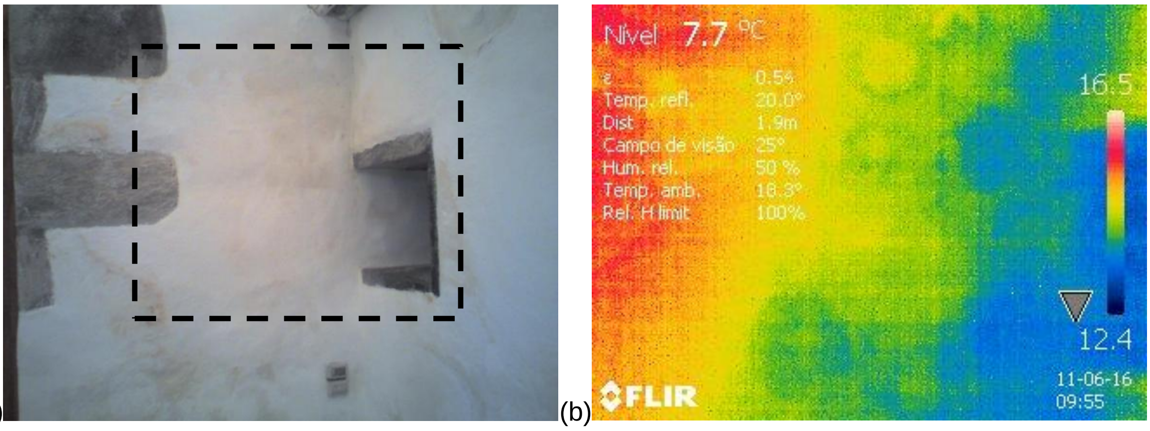


Figure 56: Extensive presence of moisture in the ground floor room

The ground floor didn’t exhibit significant damp patches around the edges as seen in Barryscourt due to the underfloor heating; however the thermo image clearly showed up underlying moisture through the low temperatures around the floor edges (Figure 57). Evident damage and deterioration to the timber supports was clear from the visual inspection and the thermography images helped to isolate causes for this damage by showing up the presence of moisture surrounding the contact points between the timber beams and the moisture laden walls (Figure 58).

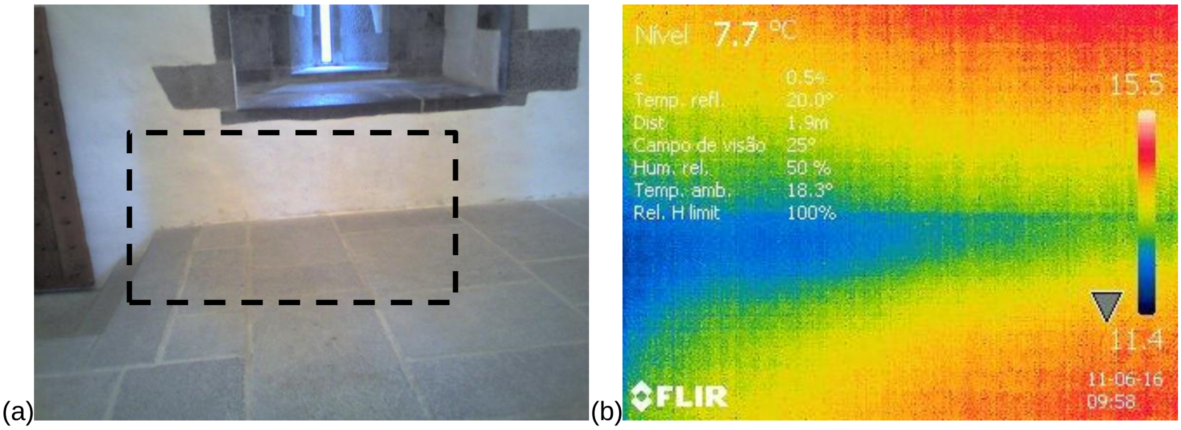


Figure 57: Significant moisture around the floor edges of the ground floor

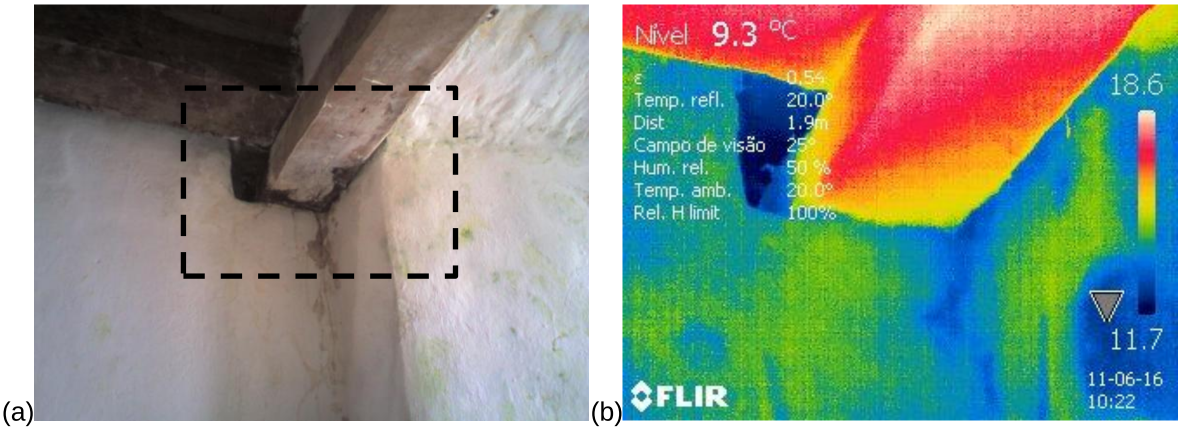


Figure 58: Moisture surrounding timber structural supports with serious dampness in the wall pocket

Identical to Barryscourt, salts were quite visible as a white ”fur” deposited on the wall surface; the thermography image showed up the underlying moisture pockets which allow the salts to migrate to the wall face (Figure 59).

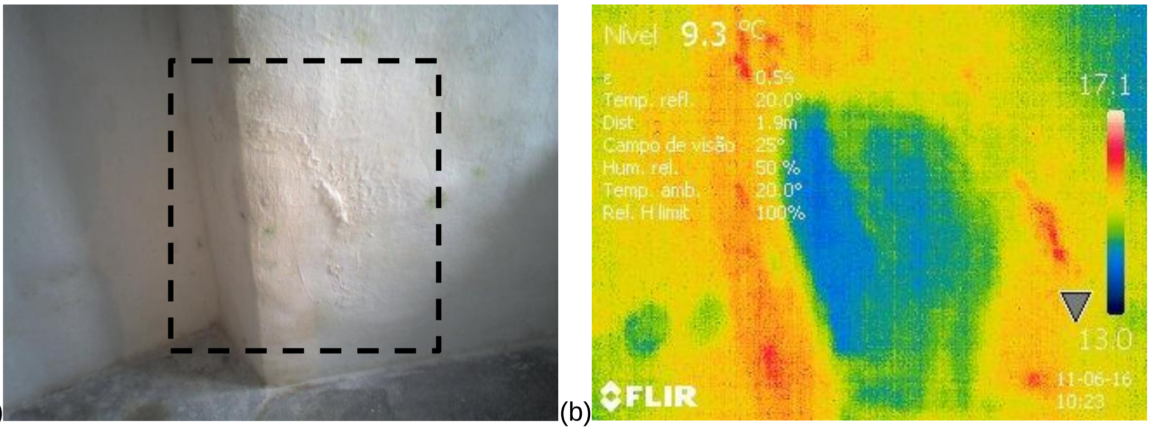
(a) 

Figure 59: Thermography image of wall region with salt presence

Staining surrounding the timber supports was visible here but the thermography image showed the region above the corbelled support stone to possess the most moisture in the region (Figure 60).

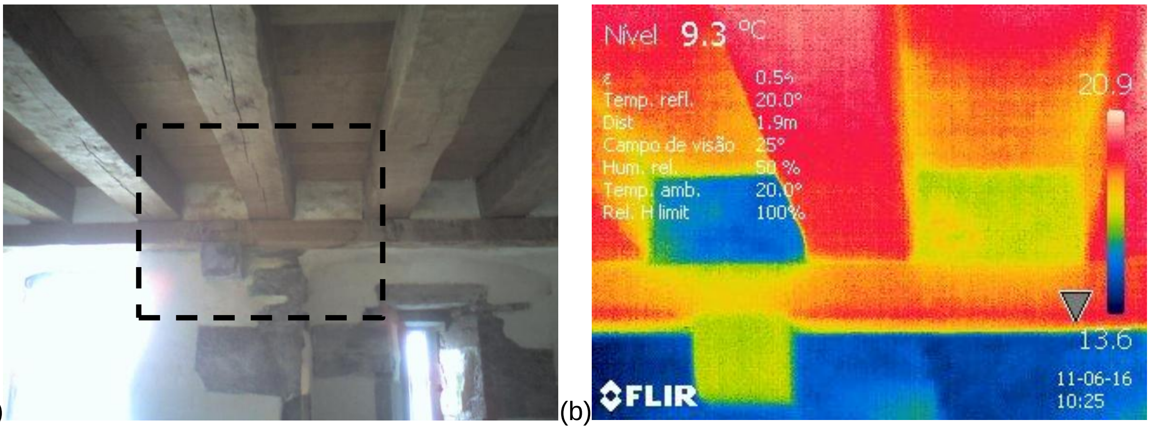
(a) 

Figure 60: Further moisture around timber supports, especially near windows

Moisture showed up in the centre of the walls, and more commonly in the upper corners of the rooms. The thermography imaging showed the severity of the ingress in the following figures (Figure 61 & Figure 62).

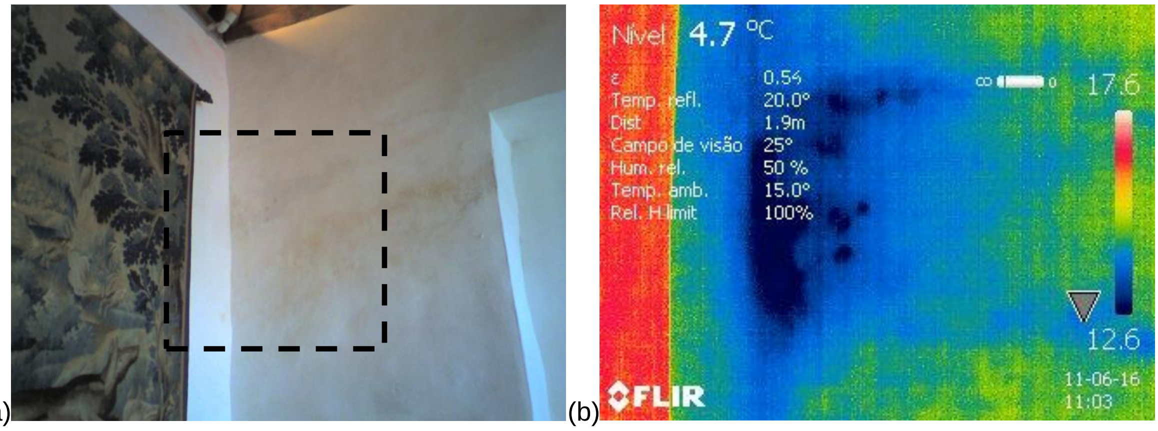
(a)  (b)

Figure 61: Moisture detectable especially at room edges

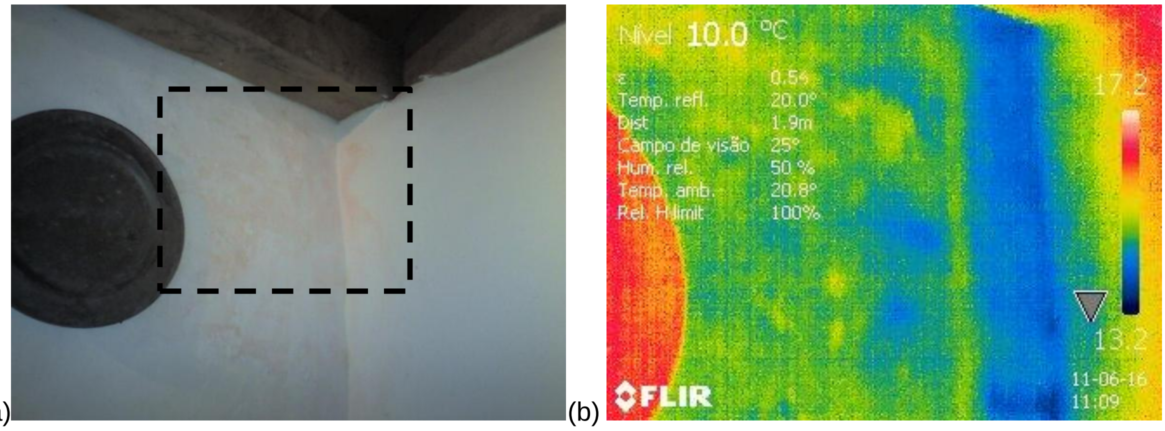
(a)  (b)

Figure 62: Further moisture at corners & wall joints from top to bottom

The thermography test on Ross Castle was particularly effective for many reasons such as the abundance of water in the surrounding grounds and due to the precipitous local climate, the walls had not been restored or limewashed for a long period of time making staining and moisture obvious but the most important influencing factor on the test was that the building had underground heating on all floors. This castle had the heating turned on whilst the test was being conducted and this had an advantageous effect for generating a temperature gradient between the interior and exterior environments. This temperature differential induces a pressure disparity causing the interior environment to “draw” the moisture inwards through the walls as the building dries. This effect makes it easier for the thermo imaging camera to detect the temperature differentials in the castles interior walls, thus yielding points of moisture intrusion and interesting results. When compared with Barryscourt, the building was in worse condition after important structural elements were exhibiting problems such as the disintegration of various wall sections and most concerning damage regarding the support joists of the third and top floor. These beams showed significant decay, were soft in places with extensive staining, mould and general degradation due to prolonged exposure to water (see Figure 58). Large pockets of salt crystals abundantly adorned the interior walls of all floors which pointed to use of cement of the use of a sand of high salt content (see Figure 59).

5.1.2 Barryscourt Castle Thermography Results

The tests were carried out with an outdoor temperature of 11° Celsius, outdoor relative humidity of 91% and an internal relative humidity of 85.4%.

Just as observed in the preliminary visual inspection, the ground floor edgings (which had very little visible moisture on this visit) displayed large regions of moisture which appear to be originating from the surrounding walls (see Figure 63). The first floor also exhibited significant underlying dampness, especially in the region surrounding the chimney flue (see Figure 64) and the adjacent barrel vaulted ceiling section. Once again, the dotted outline drawn on each photo indicates the section which was analysed and presented in the adjacent thermography image.

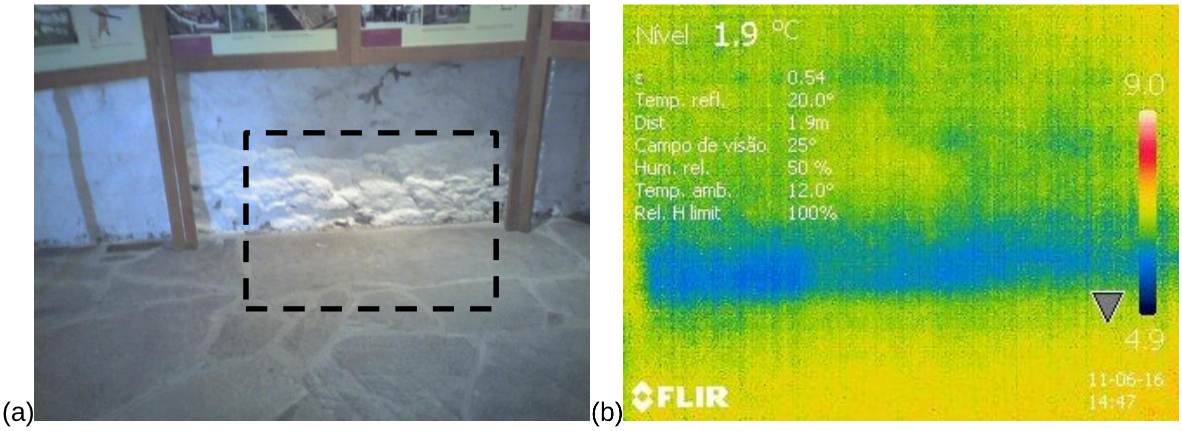


Figure 63: Moisture detected at edges of ground floor

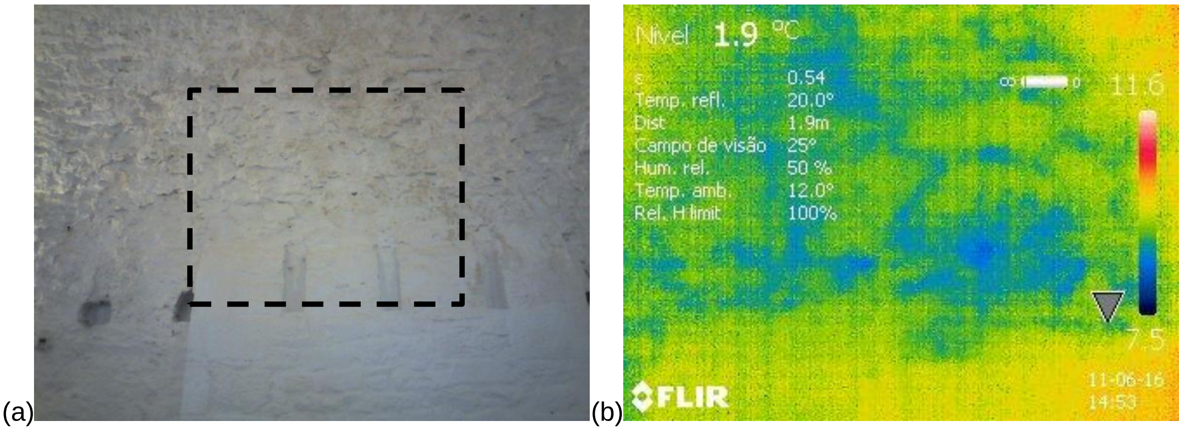


Figure 64: Staining near first floor chimney shown to have moisture presence

The surface stains were tell-tale reminders of the moisture infiltration but the thermo images certainly showed up pockets of moisture, which were even more extensive in and around the masonry indent pockets which were originally intended to support cross beams to give another level of storage. At the south and north ends of the room where the arch of the barrel vaulted ceiling meets the end walls (see Figure 65), moisture was observed in the corners, as if it had infiltrated into this section at the top, and slowly moved down along the wall edgings, as shown by the resulting thermo image. The kitchen room, as detailed earlier in the north east, had significant moisture present during the primary inspection, yet when examined on this occasion, illustrated only some of this moisture (see Figure 66) and most of the walls had large salt deposits now residing on them – this room had dried out considerably since the first visit.

(a)

(b)


Figure 65: Moisture on first floor where barrel arched ceiling meets gable walls

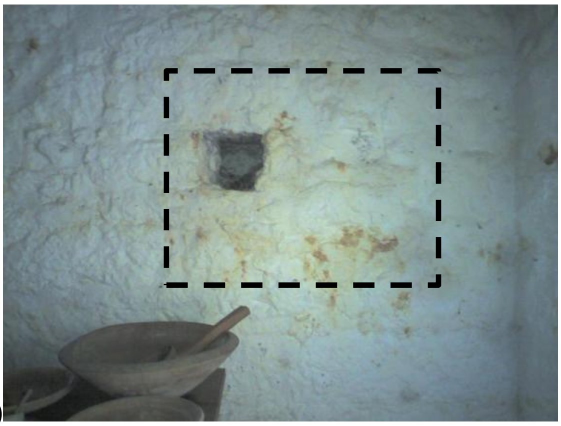
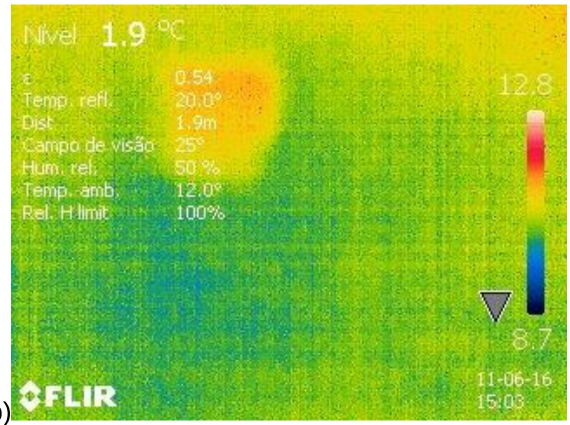
(a)

(b)


Figure 66: Slight moisture detected in walls of kitchen with wall socket showing up warmer due to thinner wall in this region

The second floor (Great Chamber) had interesting resulting images after being analysed. The west (Figure 67) and east walls (Figure 68) which show huge stain patches ended up showing large moisture traces also. Again, the most affected area was in close proximity to the chimney section, particularly on the left hand side (south side of the chimney). These patches of moisture were not located necessarily near the roof and wall connecting sections and were rather spread out through the wall surfaces in localised regions.

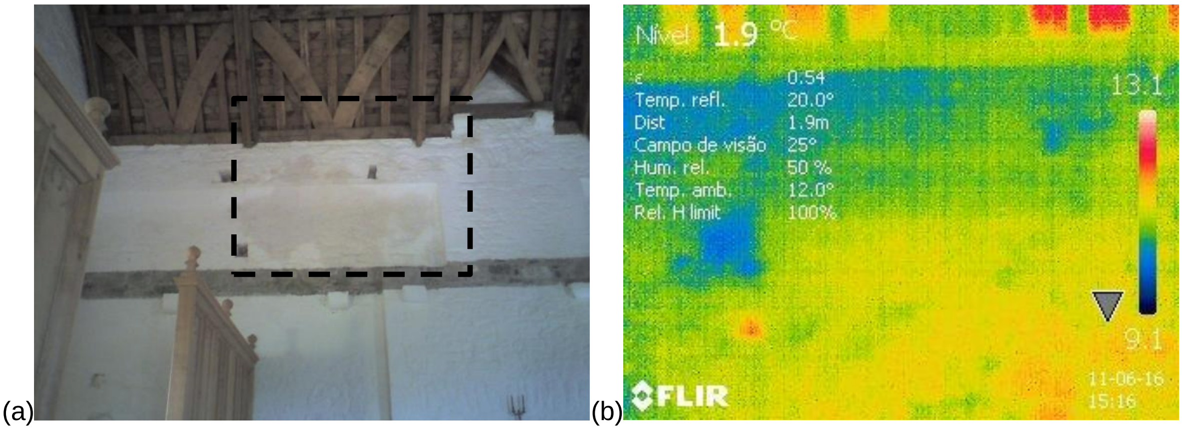


Figure 67: Moisture behind staining on west wall of the Great Chamber

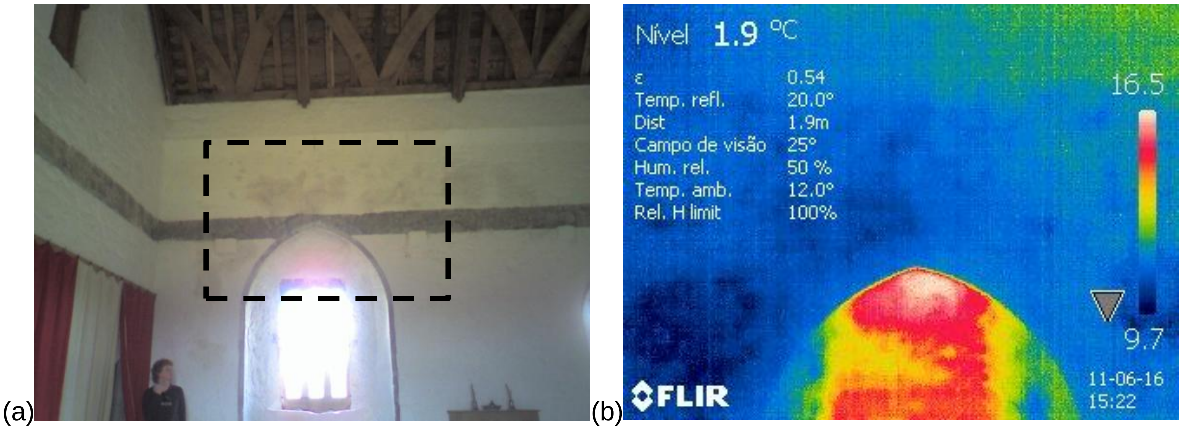


Figure 68: Moisture behind staining above northern window on east wall of Great Chamber

A peculiar patch of differential temperature was detected alongside the south side of the fireplace (see Figure 69). This patch was isolated and there was no corresponding staining it provoked scepticism whether it had anything to do with moisture at all. There is documentation and photographs showing how thieves who attempted to steal the fireplace made a hole alongside the fireplace in order to throw the mantel outside (as outlined in section 3.3.6). This hole was subsequently restored and the patch showing in the thermography image could be detecting this restoration section due to the different material used in the renovation.

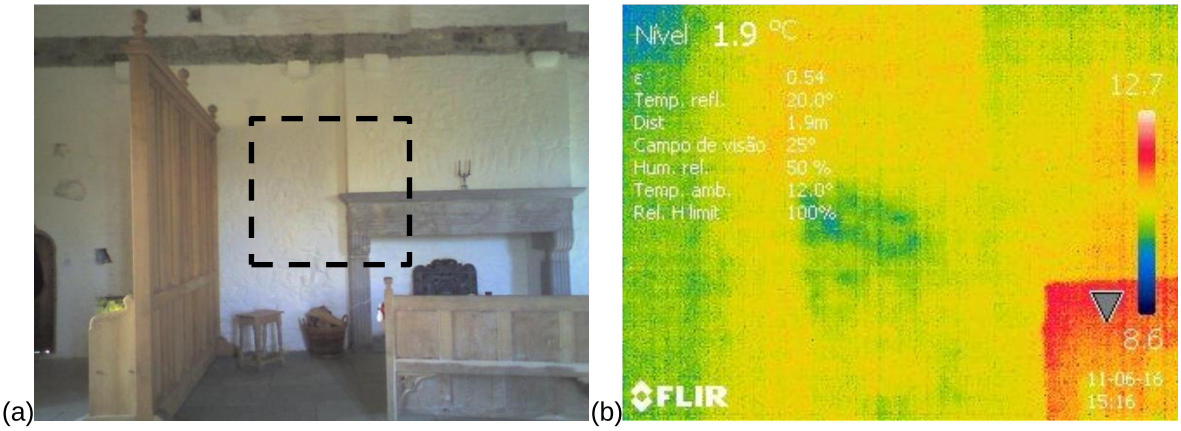


Figure 69: Thermography image showed pocket of differential temperature on south side of the main fireplace in the Great Chamber

The room with the most detectable moisture of all the rooms in Barryscourt was certainly the master bedchamber. As highlighted before, this room had been recently limewashed by the caretaker in order to cover up the unsightly moulds and green biological activity which was flourishing earlier in the year and as viewed during the primary site investigation. After being concealed, it was not nearly as apparent any more where the infiltration moisture was located and most of the sources of ingress were somewhat concealed apart from some staining in the rooms corners. The thermography camera revealed moisture in the upper corners of the room, mostly where the chimney stack meets the southern wall (see Figure 70 & Figure 71). There was brown staining in these corners; again, staining from water mixed with the oak tannins and the staining appeared to be originating from the upper corners where the roof meets the support walls. The thermo imaging gave indication of this source showing moisture in these corner positions. This water appears to be infiltrating and moving down through the masonry joints and leaching throughout the wall.

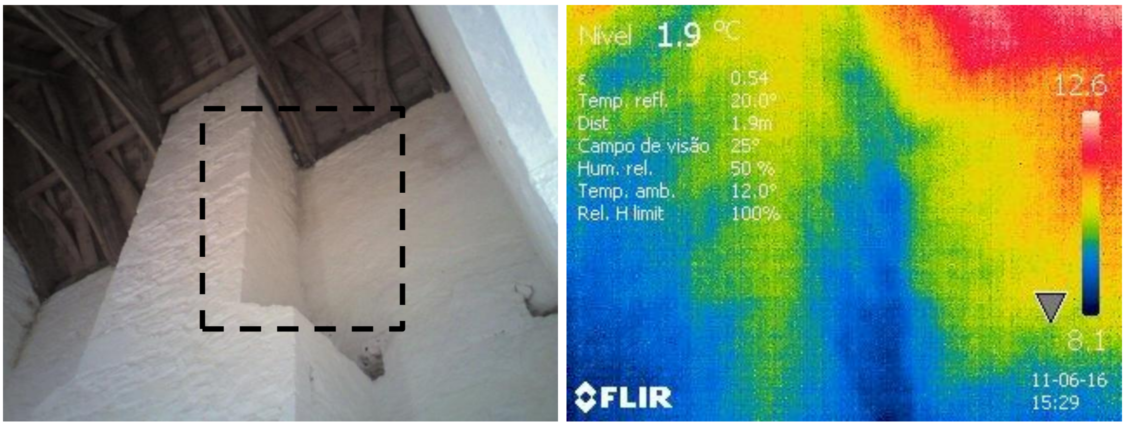


Figure 70: Moisture detected by thermography testing surrounding western corners where chimney meets the walls in Master Bedchamber

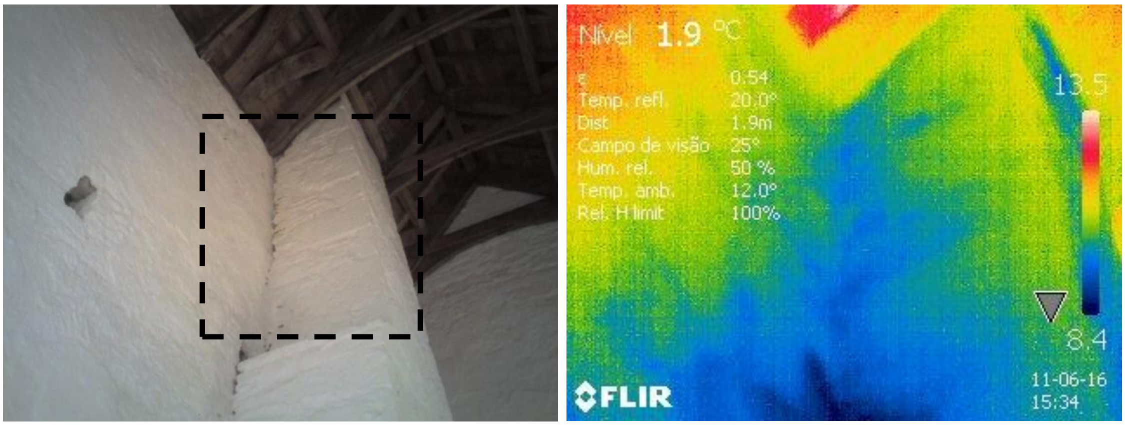


Figure 71: Moisture detected on east side of chimney

5.1.3 Thermography Analysis Discussion of Results

The testing was first of all, a good trial run for the camera itself, which until this point, had only been used in modern structures with thin walls, nothing compared to the thick walls of a typical defensive castle. The camera showed the presence of moisture and through the different trail runs, illustrated the influencing factors which yield better results, as what was seen with the Ross Castle tests and how the interior underfoor heating benefited the research. The testing on Irish castles was a baptism of fire when compared with the testing conducted in the Castle of Guimarães.

Even though the testing was conducted in the later stages of June, one of the drier months in Ireland's precipitous calendar year, the test still showed up regions of moisture throughout the building. The ground floor walls have significant internal moisture which is most evident at the wall bases, as seen in the primary investigation, at the wall edges and side flagstones. This suggests rising damp as an issue, coming up through the walls via capillary action and remaining in the lower walls throughout the year. The cyclic rise and fall of this water during the year in times of varying humidity will cause stresses to be induced in the component materials over time, causing fatigue and eventual disintegration which again was observed in the site inspection, with exfoliation and surface damage. This seems to be causing damage on the external façades also, especially on the batter wall where huge mortar loss is evident. This process could be accelerated many fold in times of frost or freezing conditions, with freeze thaw action generating large stresses that crack and damage the joint mortar forcing it out and exposing further interior regions. The lower section moisture was not the only moisture found in the ground floor rooms, but it was certainly the most obvious through the imaging. The fact that other moisture from upper sections was also present, points more to other infiltration mechanisms from the external environment such as poor mortar and percolation from regions above (seen from stained floorboards overhead).

In addition, salts were clearly evident during the second site visit when the building had dried considerably. This demonstrated that when saturated, the walls moisture keeps the internal salts soluble. Whilst soluble, these salts are not so troublesome, but rather when the wall becomes wet and dry as stated above, during the changing temperatures and climatic conditions, the salts become soluble when wet, and recrystallize when dry. This cyclic phenomenon is also harmful to the component materials and contributes to the surface damage and exfoliation. These salts may be absorbed from the surrounding soils, in a soluble form through the rising damp. However, the more believable origin is from the previous restoration materials i.e. the mortar and the contained portions of cement or salts contained in the sands used. This can be concluded since these salts occur in all floors of the building, and are not solely found in the ground floor regions.

On the first floor, moisture was also evident on most walls, especially the western façade in close proximity to the chimney flue. The vaulted ceiling had large areas of moisture especially where the vault meets the southern wall and the moisture is observed to be moving down along this joint line.

The kitchen was slightly different in the way that it showed very little evidence for moisture on this visit. What was evident upon this visit was the presence of salts again on the walls, especially near the window openings. The room had dried out considerably since the first visit and now the salts were crystallised on the surface. The surfaces had been wet to the touch in the primary assessment, in identical locations to where the salt was evident during the second visit. The warmer environment and surface temperature on this visit allows more moisture to remain vapourised in the internal air, subsequently the vapour doesn't condense on the surface.

On the second floor, the thermography testing showed large moisture patterns which were quite apparent already from the limewash staining. However, what the thermography allowed one to understand was that the pockets of moisture were not always originating from roof leaks or faults, but also that the moisture appears to be originating from the outside walls, due to its position in the centres of the walls, above windows rather than below them and around the chimney stack which would have thinner walls than the surrounding walls. This evidence points more in the direction of faulty/porous mortar joints and strengthens suspicion of inadequate mortars in the building's exterior along with poor roof drainage or gutter problems.

Another point that can be taken from this analysis is that the camera detected some sort of region alongside the fireplace in the Great Chamber. As outlined before, this could be due to different repair material which was used in the restoration and just reiterates the multi uses of the thermo camera for detecting hidden features, materials and substances. It also highlights the need for a skilled, trained and intuitive operator of the camera to differentiate between these different media and not to jump to conclusions, such as in this case, immediately assuming this patch was due to moisture ingress.

The thermography analysis of the master bedroom was the most effective. It revealed that there a water ingress at the corners of the room, and in particular the chimney corners. This encourages us to investigate the corner points, to examine the corner seals and to evaluate the waterproofing in these sections to accurately identify the problem and the mechanism for this water ingress. These leaks are not the only sources of water in the bedroom however, since the thermography showed other sections of moisture on the walls. The interior of the chimney itself has significant mortar deterioration and staining.

Without conducting this non-destructive test on Barryscourt, it would not have been possible to accurately pin point damage and sources of the effecting moisture. In this light, the thermography testing was integral to the advance of this study and the success of an accurate site investigation/inspection.

5.2 Water Absorption Test Results

As described in the previous section, the water absorption test using the RILEM tube was conducted on the exterior walls and included tests on the stone and the restoration mortar. The results were tabulated (an example can be seen in Table 3) and the time taken was plotted against the accumulated volume of water for each experiment (an example of one of the plotted graphs can be seen in Figure 72). Additionally, the rate of absorption of each material (both internal and external) was calculated and the resulting graphs were plotted against each other for comparison. The remaining test data can be viewed in the annex.

5.2.1 External/Internal Wall Tests

On the day of testing, the outdoor temperature was recorded as 15°C and the relatively humidity was noted as 69%. The indoor temperature was recorded as 15.5°C and the relative humidity was 77%.

Table 3: Data recorded for RILEM tube test 1 on south face wall - limestone

Time [mins]	Acc. Vol. [mL]	Relative Vol. [mL]	Water Absorption Rate [mL/min]	Relative Water Absorption Rate
0	0.00	--	--	--
05	0.20	0.20	0.04	1.0
10	0.25	0.05	0.01	0.3
20	0.35	0.10	0.01	0.3
30	0.40	0.05	0.01	0.1
60	0.50	0.10	0.00	0.1

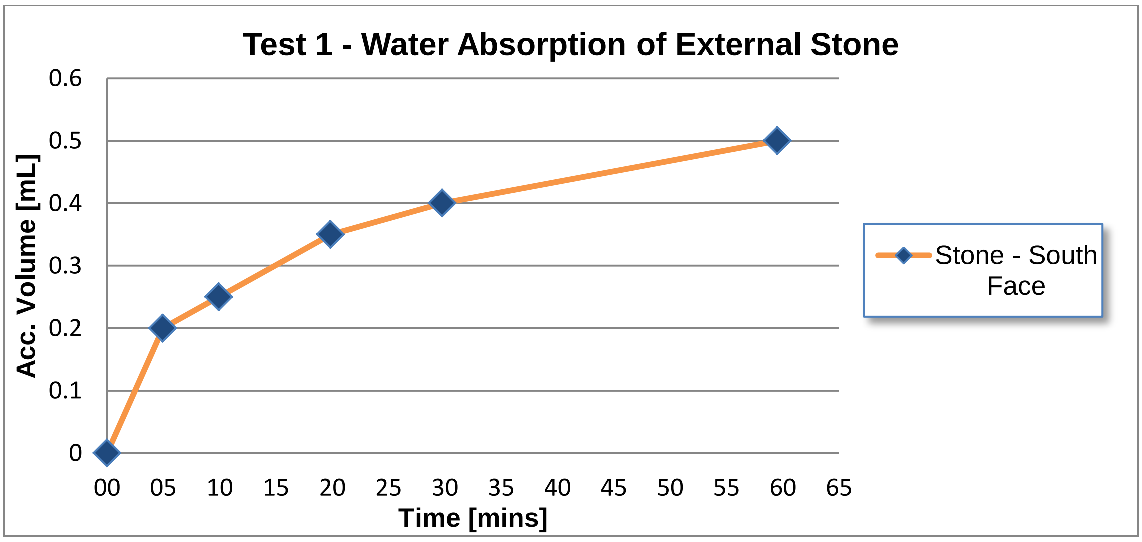


Figure 72: Water absorption of stone on south wall

5.2.2 Masonry Material Comparisons

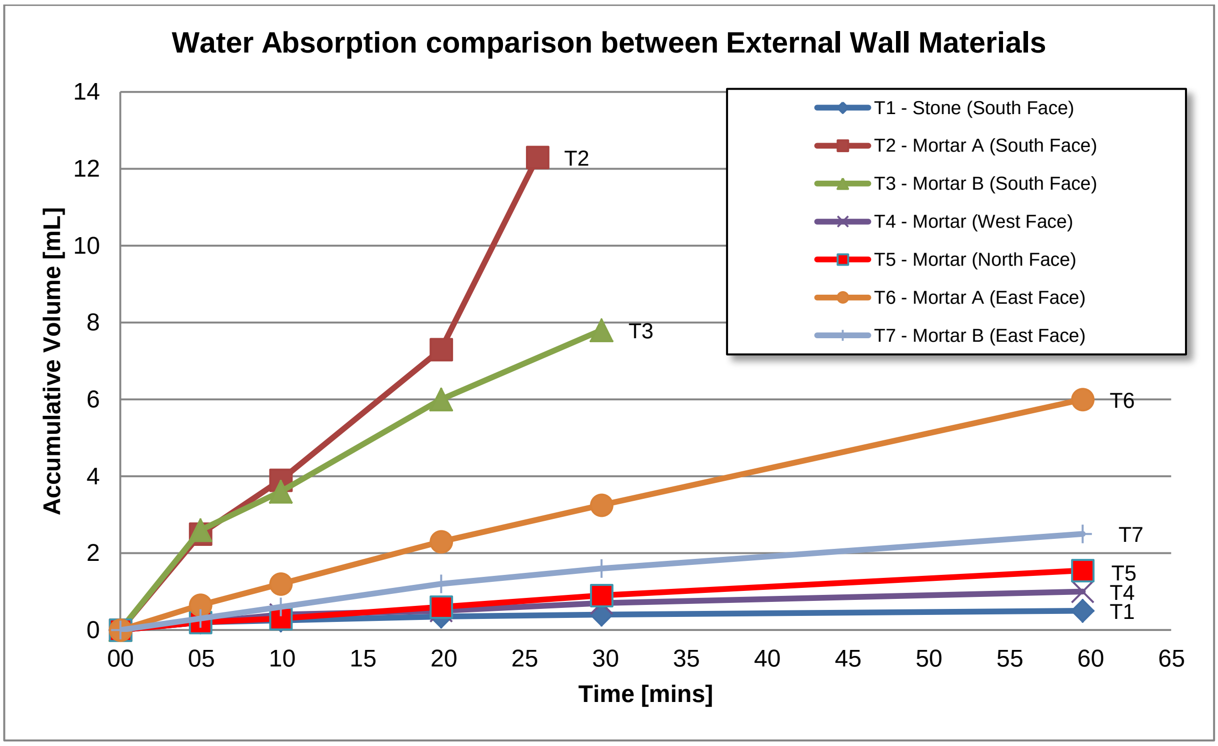


Figure 73: Water Absorption comparison between External Wall Materials at Barryscourt

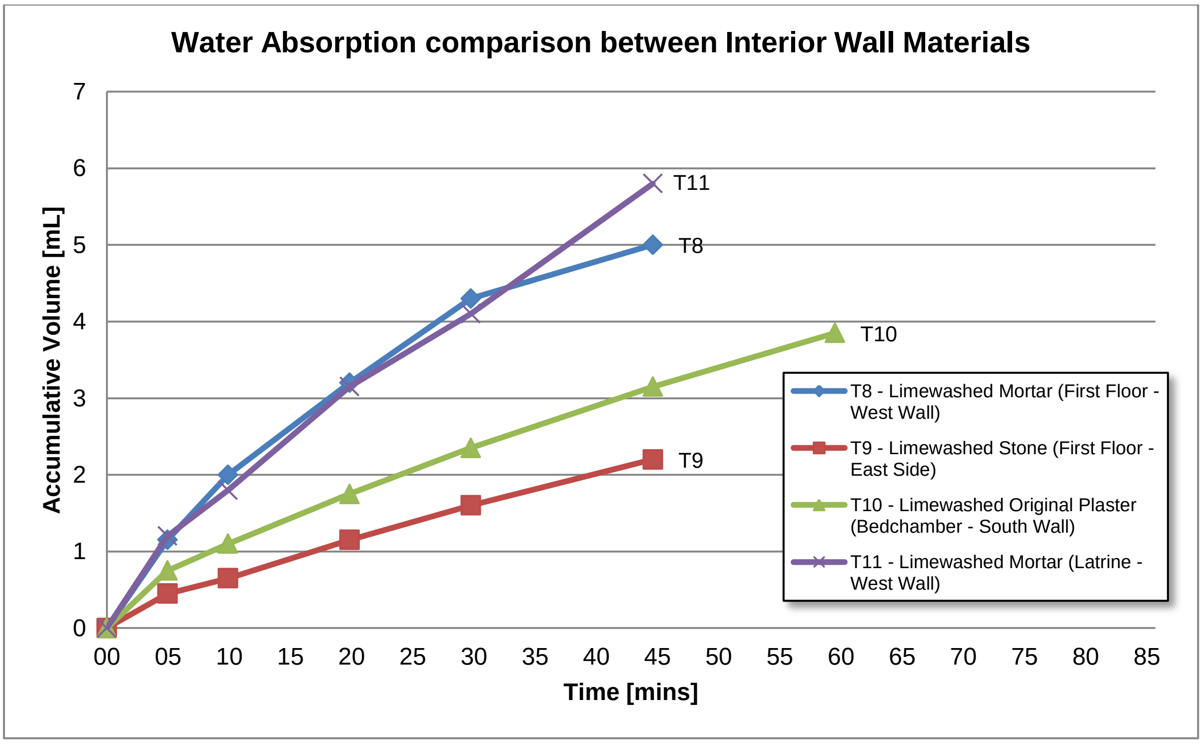


Figure 74: Water Absorption comparison between Interior Wall Materials at Barryscourt

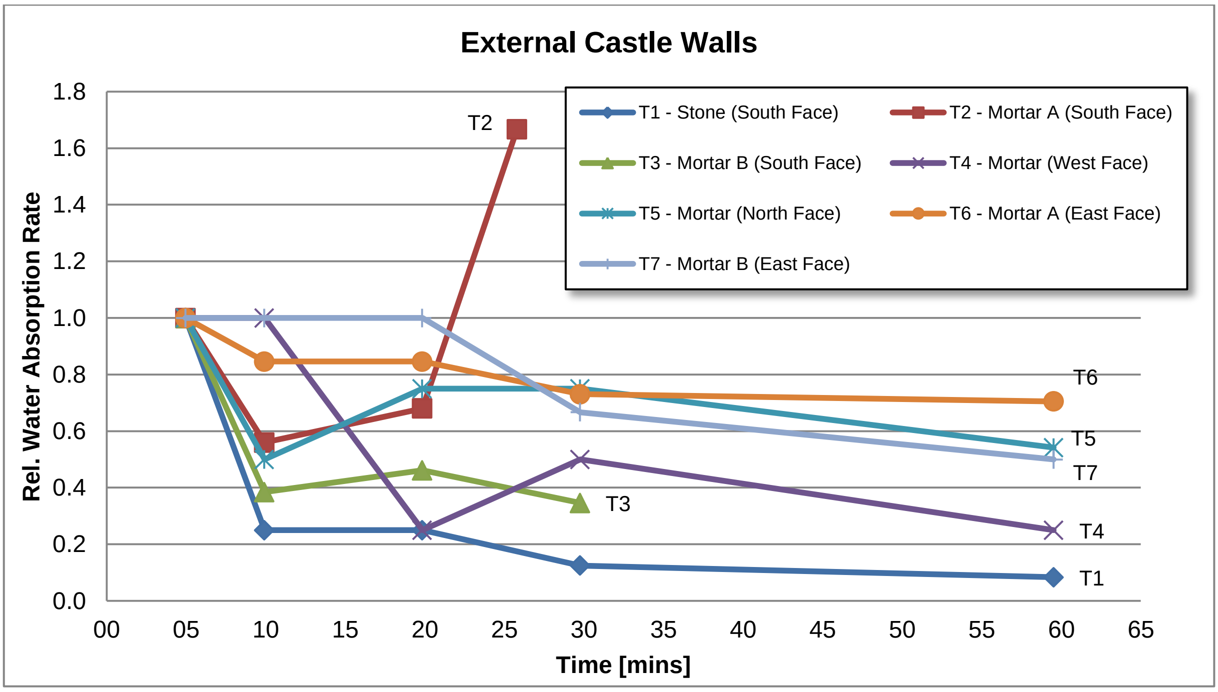


Figure 75: Comparison between the relative rates of absorption between external materials

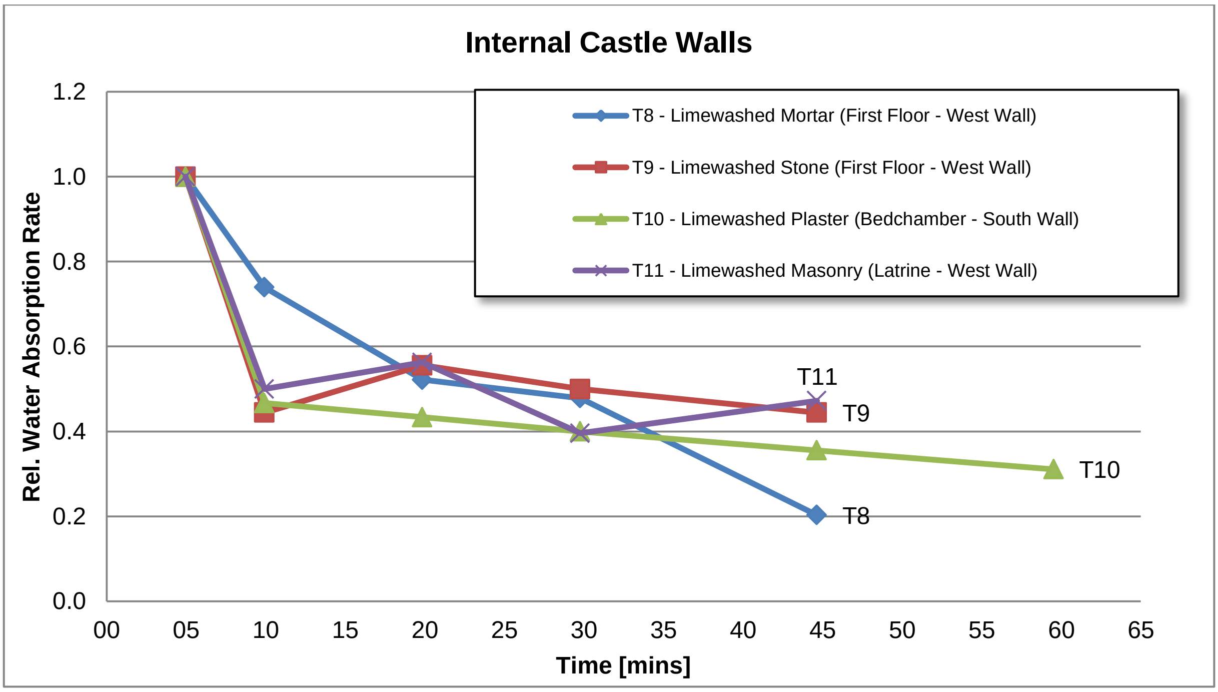


Figure 76: Comparison between the relative rates of absorption between internal materials

5.2.3 Water Absorption Results Discussion

From examining the damage and deterioration on the interior environment of Barryscourt, it cannot be disputed that the building is absorbing too much water for its own good. Although the limestone shares some very minor responsibility for water infiltration, the mechanism is most heavily influenced by the mortar, as seen through the conclusive water absorption testing conducted on the different materials in this chapter. The stone resisted best, as was expected, when plotted against all other materials. Soakage was slow and controlled and eventually the graph levelled off. Considering how the stone blocks in Barryscourt range from 0.2 metres to 0.5 metres in thickness, it is safe to conclude that the limestone isn't responsible for the moisture intrusion on the interior surfaces of Barryscourt, although its porous texture certainly assists the moisture intrusion along its borders with the lime mortar binder.

Effectively, lime mortars are porous mainly because after construction all the water mixed with lime and sand to produce (and apply) the mortar evaporates and thus, the spaces previously occupied by water become porous. Additionally, this porosity allows the carbonation of the lime to produce a hard product. It is this porosity which defines the moisture ingress at Barryscourt, and since the surrounding climatic conditions are so precipitous, the mortar is subjected to an almost relentless bombardment of water, water which is pressed against the building by relatively constant winds. The mortar as a result, displays very large absorption amounts during the water absorption testing, and really revealed the main source of the masonry's filtration faults. The poor mortar had already been observed during the primary inspection as bring sandy, crumbly and quite easily displaced. This rough texture allows moisture to adhere to the surface for longer periods of time, and under rainy and windy conditions, allows significant filtration through the material itself, into the underlying masonry and through to the interior surfaces. The outer environment drives the water through the water with the wind generated surface pressure forces the water through the lime mortar pores aided by the mortars own capillary properties. The mortar tested on the south face tended to be quite granular and rough and it was quite difficult to effectively seal the plasticine around the test area. The water absorption was also much higher on this façade when compared with the others and the mortar was massively porous when compared with the stone on the identical façade.

From Figure 75 and Figure 76, it is clear from the final values for the relative rate of absorption that the materials were not near their saturation point. The relative rate of absorption decreased in almost all materials, however it didn't reach zero for any of them (except for the stone which came quite close). This illustrates how the mortars were not near their saturation point and could have absorbed significant amounts of additional water, further illustrating how the building is acting like a "sponge" during periods of rain. Additionally to this, a series of peaks or jumps are visible along the data. These jumps in the data indicate when additional water was added to the RILEM tubes, therefore increasing the pressure on the test surface and increasing the rate of absorption. Similarly, the higher the winds, the higher the absorption rate of water into the walls mortar.

It was quite difficult to determine which type of mortar was being analysed during each test. Since the restoration project, the mortar joints have become almost visually homogenous to a large extent and staining from lichens and mould has hindered the ability to differentiate between old original mortar and new restoration mortar. The areas of obvious new pointing were too difficult to access for the testing also. Just above the batter wall where the walls are vertical were the main test positions because they were within reach and easy to observe without making an error of parallax when reading the graduated markings and water levels.

It was possible to test some areas for longer durations than others, due to the restrictions to access and working between opening hours. Some tests also leaked after additional water was added and these tests were abandoned, referencing only to the previous measurement prior to the water addition.

The tests were given a maximum timing of one hour, and testing location was then changed for another test. It is interesting to observe that very few of the graphed resulting plotted curves “level out” (apart from the stone, and west/north mortar joints) or stabilise over time to indicate saturation or a slowing of water absorption. This may indicate that the walls can absorb more water per square centimetre given more time, and perhaps, if conducted again, should be done over a two hour duration to see when the water absorption slows/stabilises.

An interesting observation on the results is that of all the mortars tested, the mortar of the western and northern façade (of the external walls) exhibited the lowest water absorption values. This was a strange finding, especially considering the west mortar absorbed much less than the other mortars, considering it is located on the wall facing the prevailing wind and rain direction, the wall which exhibits most weathering and mortar loss. Reasons for this strange occurrence may be due to the fact that this wall was already heavily wet, perhaps even almost saturated from recent rain. The testing day was the first completely dry day of the visit to Ireland (hence the reason this day was chosen), however this does not exactly mean that the wall was dry, perhaps only the surface was dry.

Additionally, the mortar on the northern façade was just as good, arguably, for the same reason. These mortars tested are most likely also mortars from the restoration project, which was gauged with ordinary Portland cement. The absorption levels were close to the limestone values, yet the quality of the mortar appeared to be no different to other surfaces. This mortar allows less water to pass through the joint than the older mortars under the same conditions. However, the harmful effects of Portland cement cannot be ignored, as seen through the abundant salt presence in the interior façades of the tower house. These salts, overtime, will cause surface damage with spalling and exfoliation of the face material. Any stresses induced in the walls will be forced through the surrounding stones, since the cement gives additional strength to the lime mortar, causing minor cracks which allow additional water infiltration. Traditional lime mortars were by nature, softer, allowing minor displacements with structural settlement whilst also allowing the underlying masonry to breathe after times of rain, encouraging vapourisation of the interior moisture. The lime content in the mortar also has “self-healing” properties when small cracking and fissures appear, soluble lime infiltrate the cracks and carbonates in the process, filling the fault and sealing the wound. Mortars gauged with cement are less porous and hamper the ability of the walls to breathe, facilitating interior condensation, as what was observed during the primary site inspection in the castle.

The original existing interior plaster on the master bedchamber’s south wall showed how this layer of plaster slows the water infiltration, as seen when one compares the water absorption of the plastered interior wall section and the naked interior wall section in Figure 74. Again, in the castles heyday, the interior plastered wall would have been limewashed further adding to the absorbent properties, holding additional moisture to the bare whitewashed masonry which now is the most common surface in Barryscourt, a surface which proved much more absorbent than the other mortars, bar the some sections of the external mortar.

As outlined before, Barryscourt was originally rendered with a lime based plaster which would have acted as a sacrificial protective layer that enveloped the castle. It was unfortunate that the testing could not include a section of the original external render but any surviving sections are very small and in awkward elevated positions on the exterior. It would be beneficial to conduct the test on this surface also to analyse the behaviour of the original rendering plaster and to show how its behaviour as survived the weathering of the past centuries.

The test accuracy could also have been improved by testing over larger areas with larger RILEM tubes to give a more global view of the masonry behaviour. Due to time, weather and access restrictions, the testing was done on specially chosen areas which only gives an idea of behaviour at those specific locations.

5.3 Monitoring Results and Discussion

After removing the monitoring data-loggers, the data was downloaded and plotted to give an insight into the internal and external climate conditions at Barryscourt. The following figure (Figure 77) illustrates the record hourly measurements for the most moisture-affected room, the Master Bedchamber.

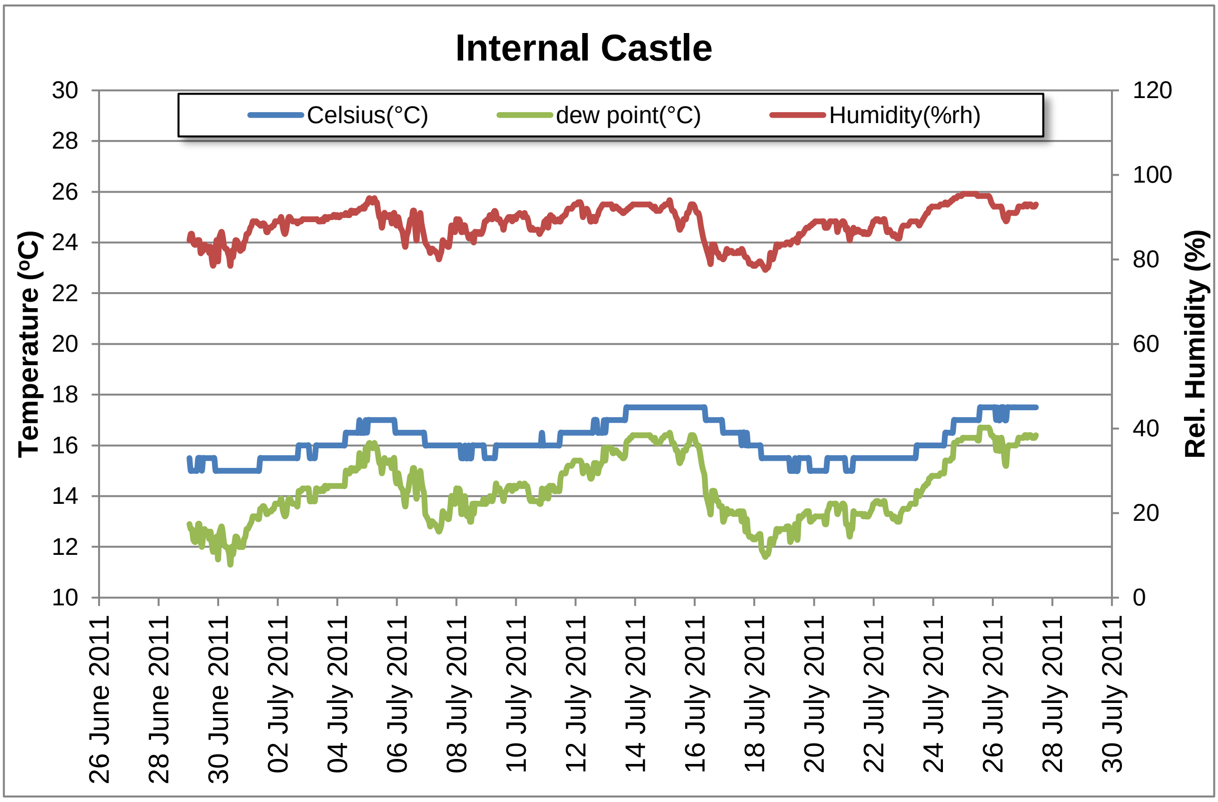


Figure 77: Temperature, relative humidity and dew point hourly measurements from Barryscourt interior - Master Bedchamber

As can be seen in this graph (see Figure 77), there is a high humidity at all times in the castle interior. The humidity rarely drops below 80% throughout the whole month. Interestingly, the dew point temperature does not equal the actual air temperature at any point during this time span; therefore no interior condensation occurred in the Master Bedchamber during this period. The temperature is relatively low and constant.

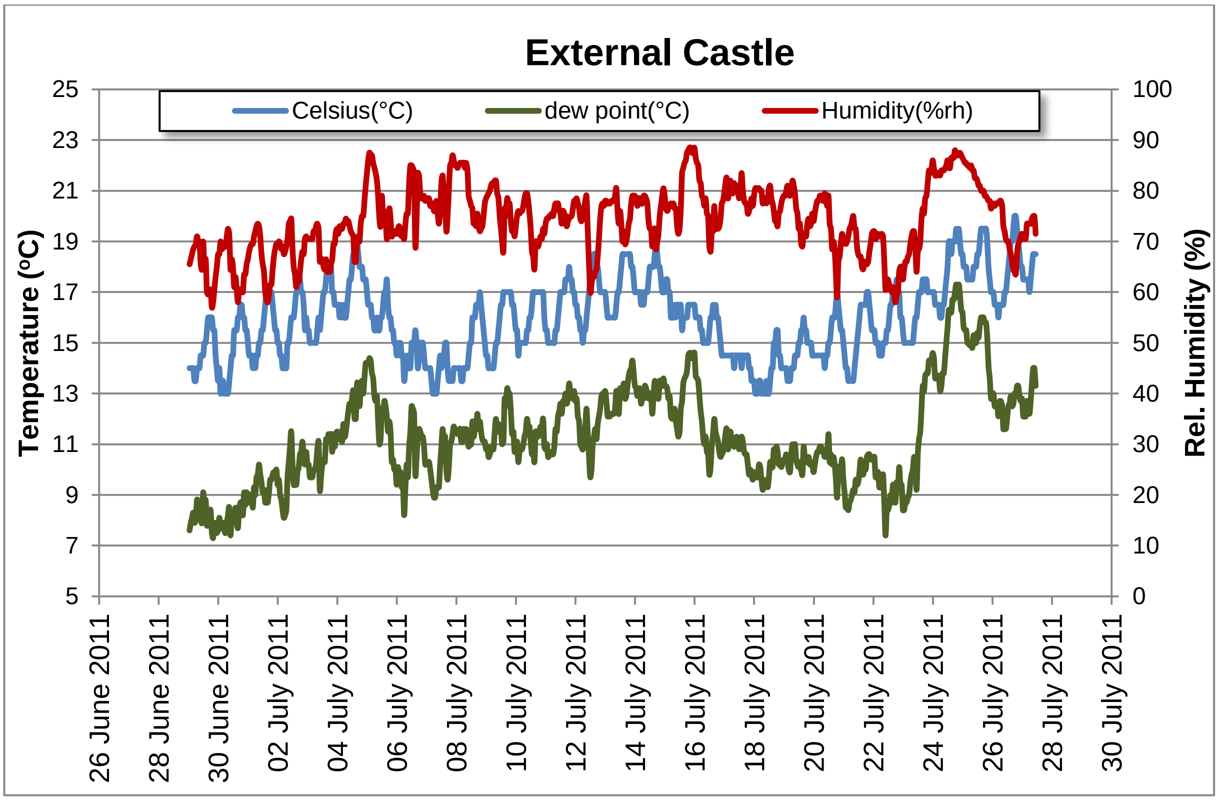


Figure 78: Temperature, relative humidity and dew point hourly measurements from Barryscourt exterior - Surrounding bawn wall

As can be seen from this graph (Figure 78), there is a more variant humidity in the outer environment. In order to compare the data from the two data-loggers, the two graphs were merged in order to observe the behaviour of the internal and external environments relative to each other during the same time period (see Figure 79).

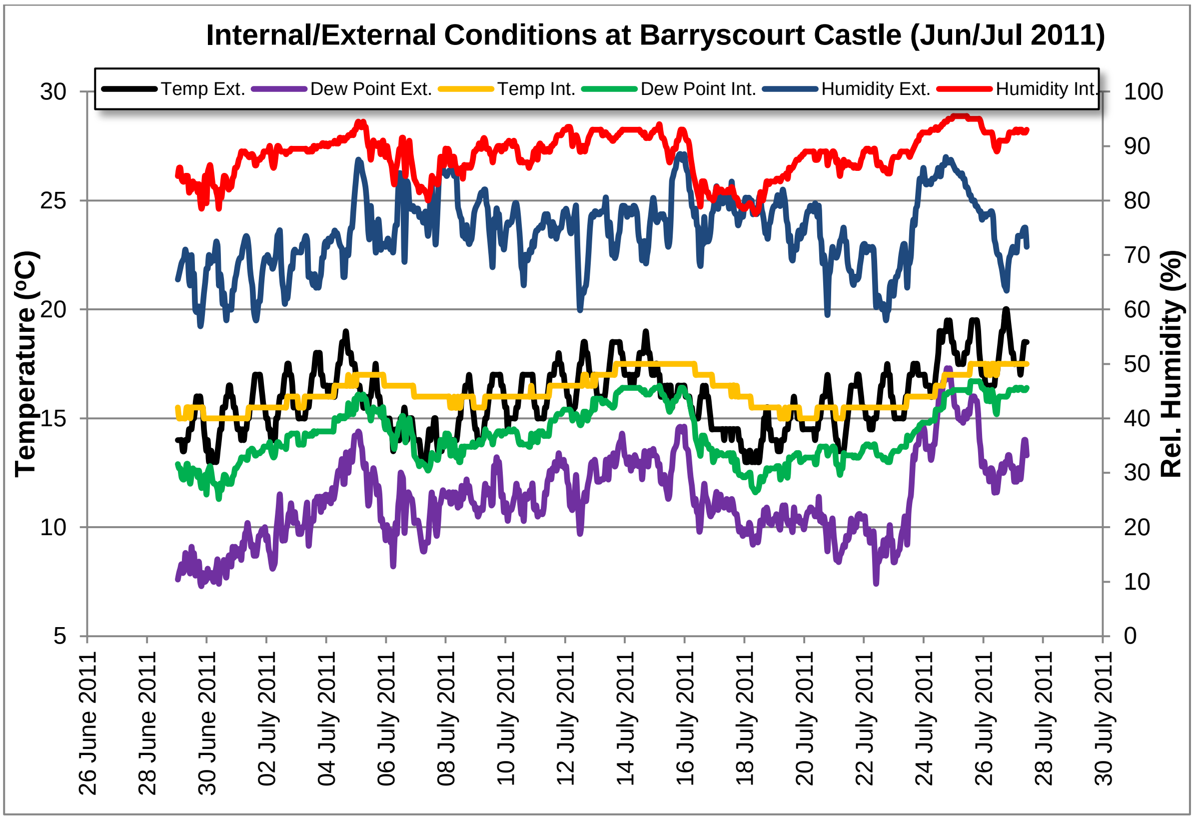


Figure 79: Comparison of the conditions recorded by the interior and exterior data-loggers

From this comparative graph, a number of observations can be made about the behaviour of Barryscourt during a typical Irish summer month. First of all, it can be reiterated that there are no condensation problems in this period since the dew point is lower than the interior temperature. Ideally, in order to conclude that this is the case, the surface temperature must also be recorded to be sure that the dew point is always below the interior material temperatures, however, since both the internal and external temperatures are similar, and both are lower than the dew point temperature, it is safe to assume there is no condensation. From Figure 79, we can also observe that the external and internal relative humidity is always high, but more importantly, the humidity recorded inside the Master Bedchamber is higher than the humidity recorded externally. This illustrates how the building is unable to properly dry out even during the summer months. Even with high ventilation rates, since the external humidity percentage is so high, this effectively hinders the room's ability to release its humidity through ventilation. As a result of this, the water vapour of the interior environment remains in the room, unable to escape and this continued presence in the interior atmosphere provides the necessary moisture required for living organisms and biological activity to flourish, as seen by the rampant moulds and fungi on the walls of the room. This biological presence leads to damage in all materials of the room including the walls, furniture and surface materials (plaster). Also, the interior temperature is low, but relatively constant, and increases slightly when the external temperature rise. This illustrates the high thermal mass effect of the room as it rises from 15 to 17.8^{o}C.

6 MOISTURE INTERVENTION AT BARRYSCOURT

6.1 Preservation of Barryscourt

The previous sections of this report detailed the background study of the castle, its construction phases, restoration procedures, present condition by qualitative and quantitative surveys and measures, and specified tests procedures in order to gain a detailed understanding of the buildings behaviour due to its surrounding climate and typography. Section 3.6 of the 2003 ICOMOS "Principles for the Analysis, Conservation, and Structural Restoration of Architectural Heritage" charter clearly states, "*The design of intervention should be based on a clear understanding of the kinds of actions that were the cause of the damage and decay as well as those that are taken into account for the analysis of the structure after intervention; because the design will be dependent upon them*" (ICOMOS, 2003) Having firmly established that Barryscourt Castle exterior and interior problems stem from moisture ingress, a full intervention outline was developed to make recommendations on suitable measures to contravene the sources of water infiltration and to ensure the safeguarding of the monument for present and future generations.

Barryscourt is one of the 1057 documented tower houses left standing in Ireland today as recorded by data from the Archaeological Survey of Ireland. As described in earlier sections, Barryscourt structure and construction is an advanced development of a medieval Irish tower house, and is also typical in the manner in which is suffers due to the Irish precipitous climate. It is also one of the few which has benefitted from a comprehensive restoration project to protect its important historical significance for the enjoyment and education of present generations. The use of this fortified dwelling has changed from everyday use in medieval Ireland as a both sheltered household for, dining, sleeping, protection to a present day monument of a historical way of life of our ancestors. Barryscourt tower house now stands, as a museum to a way of life, but also as a document of Irish history, engineering, architecture and craftsmanship. It is important to value this structure as a historical construction which is tangible document of Irish engineering and architecture which must be preserved and protected from any damaging agents or avoidable deterioration.

By confronting the damaging issues which continue to degrade the building, and in accordance with the principles of conservation, this intervention plan could be applied to other tower houses which dot the Irish landscape, and who also suffer due to moisture infiltration. Admittedly, most tower houses are in a far worse condition than Barryscourt; Barryscourt was chosen for rehabilitation for to its largely intact structural shell and its position in the upper echelon of surviving historical Irish constructions. However, the tower houses under control of governing bodies, private ownership, or tower houses which benefit from future reconstruction/rehabilitation projects can use the intervention techniques as outlined to help combat moisture infiltration in the structures to ensure longevity and sustainability in the buildings lifespan. As observed during the Ross Castle inspection, the building is suffering from almost identical moisture infiltration problems, and even to an even more serious extent with the decay of timber support elements and global surface disintegration. Presently, these castles suffer due to the moisture, but it is seen and regarded as part of the buildings typology. This unacceptable “laissez faire” attitude to moisture infiltration must be first combatted, to educate that these affecting problems can be tackled and stopped at the source. These buildings were not designed to have water pouring down the spiral staircases during winter, to have widespread vegetation growing from any available gap, to have staining and moulds throughout the structure, but were rather meant as protected homely dwellings. A respect for the original intended use of the building must be implemented not only for the benefit of the building for longevity, but also in homage to the craftsmanship and engineering prowess which evolved over centuries to build a structure which continues to endure today.

In the following section, an overhaul intervention outline has been devised to deal with Barryscourt’s problems, which almost all originate from its moisture infiltration. Starting with the faulty roof, the problems are tackled from top to bottom in a systematic order eliminating the sources of water ingress through every stage. All intervention techniques are constrained by the framework surrounding the codes and guidelines as stated in the ICOMOS charter and not to compromise the integrity and historical context of the building.

6.2 Key Sources of Water Infiltration

As detailed in previous sections, Barryscourt tower house suffers due to Ireland climate for a range of reasons, all of which deal with the issue of water infiltrating through key points in the building. The contributing factors have been briefly summarised as:

- Poor Roof Sealing: The source of water infiltration through the upper structure was identified as roof leaks, particularly in the north-eastern tower. The other roof sections are not without their problems with new staining obvious under corner regions;
- Chimneys: Both chimneys were capped with a limestone capping stone; however both chimney flues are experiencing widespread moisture infiltration which percolates down into rooms below;
- Rising Damp through Foundation Walls: The lower regions of the structure such as the batter wall and the lower sections of the ground floor are suffering from rising damp, a problem which assists the transportation of salts and causes rapid deterioration of the lower regions of the wall, as detailed in the preliminary site inspection;
- Bioactivity is rife on both the external walls and in specific sections of the interior environment causing problems with the mortar;
- Harmful Mortar: The walls of Barryscourt were unfortunately pointed with a lime based mortar which was gauged with cement during the restoration project. The presence of this poorly chosen mortar is causing permeability issues throughout the structure and has contributed to the salt presence throughout the structure causing additional surface exfoliation problems.

The ICOMOS charter clearly states that *“therapy should address root causes rather than symptoms”* (3.1, ICOMOS, 2003). The symptoms of water infiltration displayed throughout the castle, led to this study and combined with the inspections and testing, it was then possible to isolate and identify the sources of water ingress. By identifying the key sources, the problems at Barryscourt can be properly addressed rather than covered up from view, only to return months or years later in a more serious state of disrepair. These main infiltration causes as summarised above shall be confronted with thorough and rigorous attention in the following intervention proposals to halt moisture ingress and allow the building to operate as a sealed (but breathable) unit whilst remaining true to its cultural identity and maintaining its historical integrity.

6.3 Intervention Proposal:

The problems at Barryscourt, as summarised above, are all linked and work as a system which encourage water infiltration. The most predominant factor affecting the west side of the building is the prevailing wind and rain which drives from this direction. The side walls were more heavily weathered and the mortar was far more granular and crumbled on western section (especially on the western wall near the southeast tower). The roof is causing grave problems on the northeast tower and the remaining wall walks of the main block are rampant with vegetation and suffering from general neglect. The absence of the original protecting lime render on the castle’s walls has exposed the building to the elements, and the masonry mortar which was uncovered following the disintegration of the render, is too either too porous due to weathering, or is harmful due to its cement content.

The conservation plan devised for Barryscourt includes a series of interventions which comply with the international conservation guidelines, and is outlined as follows:

6.3.1 Roof Section:

Removal of Vegetation and Organic Material

The wall walk sections of Barryscourt’s roof has a thriving biological scene with large plants, mosses, lichens and organic debris blocking the evacuation of rain water and interrupting seals and waterproofing measures. The larger plants which are rooted in many corners and in between the lead flashing should be removed and all larger vegetation should be sprayed using a mix solution of glyphosate biocide and water. Roots should be carefully removed from masonry joints in order to ensure the surrounding masonry does not become loose or displaced. Lower plants and vegetation, such as moss and lichens can be treated using rags or absorbent cloths soaked in a quaternary ammonium salt product or a mild biocide, which are then draped across the bio organisms. This process should be repeated after the project has been completed and all sections have been tended to.

After vegetation has been exterminated and removed, all loose dust and debris, organic and inorganic, must be removed gently and all treated areas must be thoroughly cleaned using a mild pH neutral detergent and water mix and gently scrubbed clean using a nylon bristle brush. After all surfaces have been cleaned a thorough rinse is required or all sections. All recommended chemical products should comply with the European Biocide Directive (98/8/EC). All sections of the roof require the attention and treatment as outlined above.

Lead Flashing/ Roof Seals Inspection & Repair:

The next aspect of the roof which warrants attention and repair is the lead flashing (see Figure 80). Starting at the top of the lead flashing and counter flashing, all lead panels, overlaps and folded joints must be inspected for further vegetation and organic debris, splits, corrosion and poor fixings. After all foreign substances have been removed, the lead must be checked to ensure correct overlapping of no less than 10 centimetres between lead leaves. Overlapping joints and meeting points must be checked for correct folding which allows water to run down the surface of the upper leaf down onto surface of the lower leaf without any moisture intrusion (Coote, 1993). The gable ends of the main roof, where the lead flashing is woven into the lime mortar adjacent to the capping stones, must be checked to be free from cracks and secured rigidly. Where the lead leaves underlie the saddle stones, the surrounding joints must be checked for cracking or voids left from vegetation removal. These joints, if damaged, must be replaced using a suitable lime mortar which will be detailed in a following section (6.3.2, *Replacement of Barryscourt mortar*).

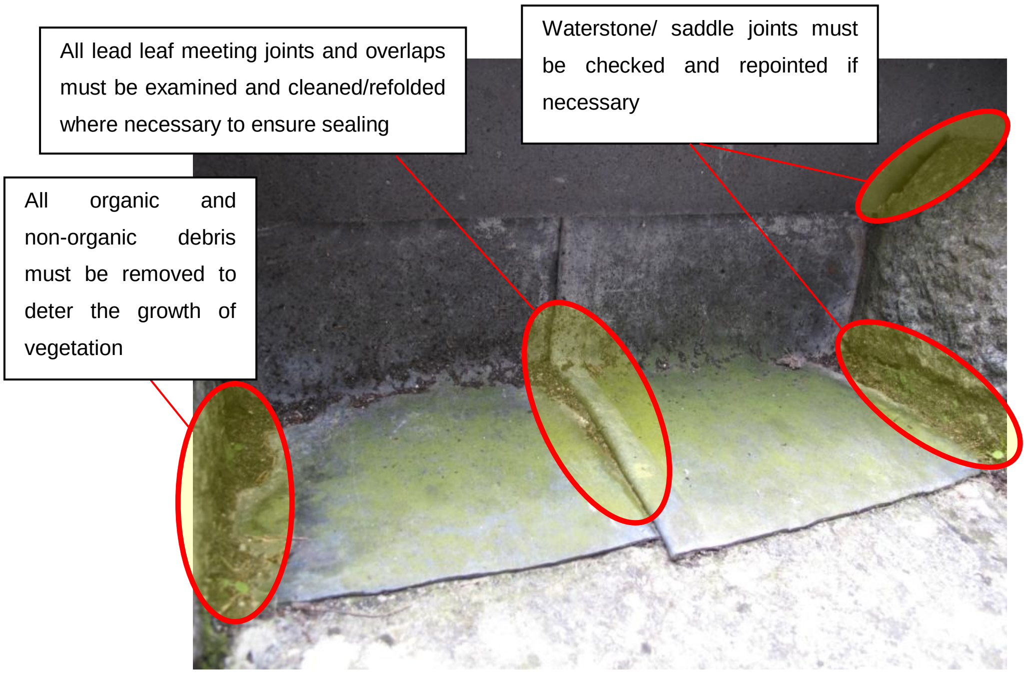


Figure 80: Lead flashing and open mortar joints which require attention

Repointing of Joints:

After the surfaces have been treated with the relevant biocides, sections of damaged or degraded mortar should be removed and raked out at a depth of twice the width of the joint (roof joints are approximately 2 centimetres in width), in order to make way for a replacement mortar. The use of power tools must be kept to a minimum in order to protect the surrounding stone block units.

Where the lead runs down the back of the saddle stones, the joint between the lead and saddle must be sealed using an appropriate lime mortar (to be detailed in following section).

At the moment, the east and west sides of the main roof are the only sections of the roof to benefit from a drainage gutter shoot. This cast iron gutter is too small for the size of Barryscourt's main roof and the steep pitch is allows water to enter at such a rate that a deeper gutter is required. The two existing gutters should be removed and discarded. The underlying fascia can then be inspected for vegetation, voids, cracks and poor sealing joints. These features must first be tended to along with the underlying lead flashing. Then a painted cast iron half-round deep-flow gutter pipe should be fitted using corresponding painted cast iron fascia brackets to affix the gutter to the lead facing that underlies the roof eaves. The brackets should be screwed directly into the lead facings and sealed using plastic/rubber capping plugs. The gutter affixed on the east side of the castle should fall/slope from south to north, with a draining downpipe connection at the northern end. This drainpipe can run down alongside the northern most saddle stone to the first dripstone. The pipe can then be run out through this exit and down the corner between the main block and the northeast tower (see Figure 81).

The guttering would also benefit from a fitted strip of anti-pigeon spikes (galvanised steel) which can be fitted to the bottom of the gutter to deter birds from nesting in the gutter systems, case which was observed during the visual inspection.

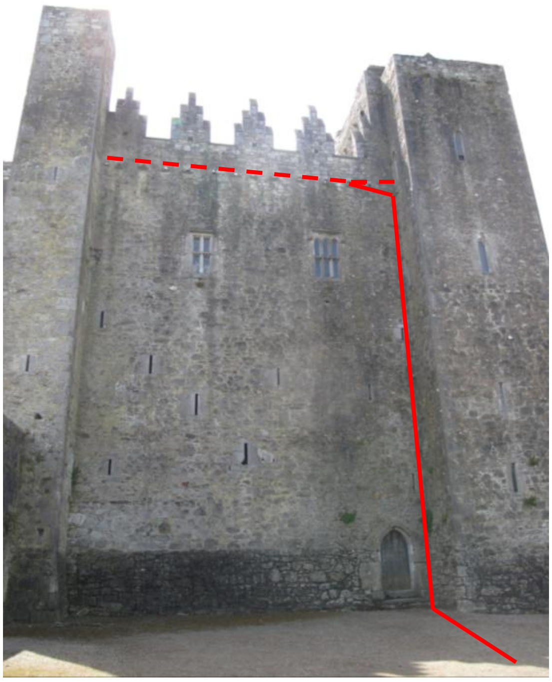


Figure 81: Proposed new gutter position with corner downpipe which evacuates through northern most dripstone

As detailed in a previous section, the west sides gutter is drained via two built in downpipes which run inside the external wall. The gutter on this side should be replace with the half-round deep-flow gutter pipe also in order to efficiently catch the runoff rooftop rainwater, and the two existing downpipes should be adequate for water evacuation.

The northeast tower roof is the most critical in terms of leaks and broken seals, as seen during the visual inspection and through the observed moisture damage in the master bedchamber and chapel during the primary site inspection and the thermography analysis. Just as what was described for the other roof sections, all vegetation and biological activity must be carefully removed, surfaces must be treated and surrounding sealing joints must be raked and repointed using the suitable repair mortar. All flashing must be examined and checked as was described earlier. It was observed during the earlier roff inspection that some parts of the lead flashing were sealed with silicone, a modern, short term sealant solution to voids and gaps which deteriorates over time and decays more rapidly in direct sunlight. This had obviously occurred since where it had been applied was open to the elements and joints between lead leaves were left open to water infiltration. This silicone must be removed wherever it is found and the lead leaves must be folded over each other correctly, as is done on most other sections. This short term solution of silicone was testament to the poor quality workmanship of the lead joints, especially over the northeast tower, leading to the extensive moisture intrusion. At the southern foot of the eastern gable end over the northeast tower, a rectangular hole was open to the elements also with no attempted measures to deter water or debris. The hole is clearly visible in the earlier section in Figure 45. This hole should be cleaned out; the roof felt which is haphazardly stuffed into the hole must be totally removed. The hole should be entirely sealed using an appropriate mortar and tapered to tie in with the surrounding masonry, with a crest ridge to defer water down each side and away from this problematic corner.

The seals around the waterstones and saddle stones must be address, examined and repointed if necessary including all joints where lead leaves were woven into the lime mortar. Cracks, voids and openings must be raked and cleaned out with the careful removal of any loose or crumbled debris. All sections must then be repointed and sealed against water intrusion. The most obvious and necessary alteration that must be introduced to this tower and also in the case of the southwest tower is a new active cast iron gutter. A standard cast iron gutter (with corresponding fascia brackets) should be positioned along the north roof ending and either side of the chimney on the south side of the roof (The roof pitch is not as steep at the buildings main roof and the roof catch area is significantly smaller also). The gutter on the north side should be positioned to slope from east to west along under the last course of slate, and a collecting downpipe should run the evacuated water out the southernmost dripstone of the west façade (see Figure 82).

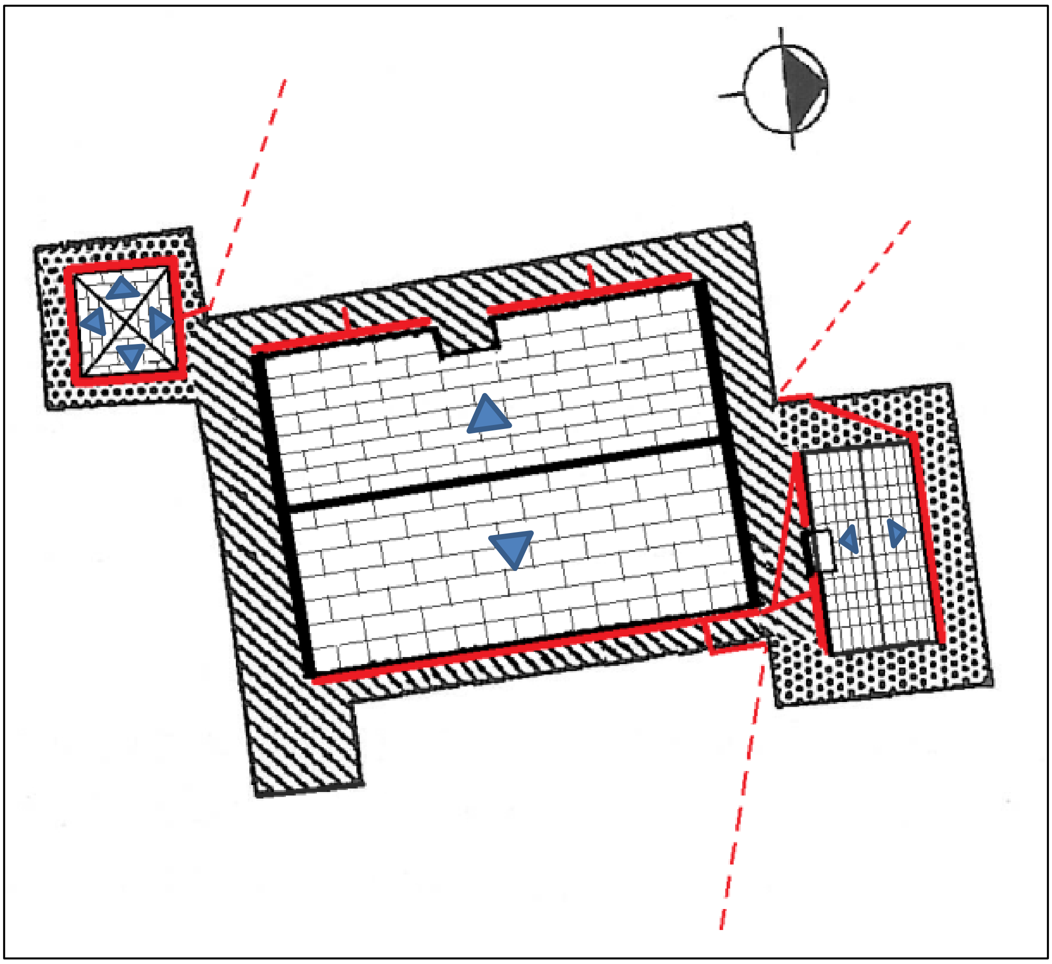


Figure 82: Rough plan view layout and schematic of new gutter/drainage system

The downpipe should then run down the corner between the northeast tower and the west wall and out away from the structure to a region of suitable drainage. The gutter fitted under the eastern section of the south roof should be drained out through the easternmost dripstone of the south façade and should run down into the downpipe of the eastern main roof section. Therefore only one downpipe is required on this side and it is connected into the eastern evacuation downpipe. The water drained from the small section of gutter on the western side of the bedchamber chimney can be connected to the eastern sections evacuation downpipe.

The lead curtains which cover the seal between the gable ends of the roof over the northeast tower must also be replaced since they are loosely secured into the gable wall by insufficient mortar which is cracked and decayed also (Figure 44, left picture). The lead veil seems to have been originally intended to force water draining down the gable wall out from the wall itself towards the dripstones. However it now hangs over the saddle stones but allows moisture do be blown up under the lead. The underlying mortar is wet and organic debris is common. This damaged mortar and debris should be removed, the joint raked and replaced with a lime mortar. This lead must be removed and replaced with a fitted section which overlaps both the water stones and the saddle stones, and lies flush with the stone allowing effective sealing against the stone face.

The southwest tower roof is pyramidal in shape and also does not have a gutter presently. This roof should have an all-round standard cast iron half-round gutter pipe fitted also and the draining pipe should evacuate out the easternmost dripstone on the north façade and down the corner between the main block and the tower in question.

It is important to remember that the roof wall walks are hidden from view behind the restored battlement and parapets, therefore hiding all interventions introduced in the roof. Although hidden, it is important that more long term materials and methods of drainage are used, such as cast iron instead of plastic. A well fitted cast iron gutter and drainpipe system will work equally well as a plastic gutter system, and would prove to be more durable and suitable for high winds which are endured at this height at Barryscourt and also in "tying in" with existing features already installed on the castle.

Additional Optional Intervention Proposals for Roof Sections:

The wall walk water stones do not have a steep draining inclination and their surfaces are quite flat, allowing rainwater to spread out to the edges when it flows across the stone. If the stone were chiselled to have a gradual curve, the water would be naturally funnelled into the centre of the stone from the edges and away from the mortar joints between the waterstone and the saddle stones, lessening the threat of infiltration. This could be done quite easily by a trained stone mason on each waterstone. This would accelerate water evacuation in times of heavy rain and help to keep joints clear and un-weathered by passing water.

6.3.2 Main Building:

Removal of Vegetation and Organic Material:

Vegetation is found dotted around the structure. Before any further work is conducted on the external wall façades of the castle, this vegetation should be removed and any holes and voids where roots have caused damage must be raked out and repointed. Removal of vegetation should be managed as detailed in the previous roofing intervention section.

Replacement of Barryscourt Mortar:

This project and the associated inspections and tests have shown the existing mortar to be having a harmful effect on the buildings component materials and its performance to precipitous conditions. Although mortars gauged with cement are harder, have quicker setting times with less permeability, these seemingly advantageous characteristics actually cause harm to a traditional building which was designed to be built using traditional lime mortar. Lime mortars allow the building to breathe, wicking internal moisture to the external environment through their porous structure, allowing minor shifts in the structures movement thus preventing cracks, and self-healing minor internal cracks through natural carbonation.

The restoration project which took place in Barryscourt from 1996 used a lime mortar which was gauged with cement (9:2:1 sand/lime/cement mix). This was a popular restoration mix at the time, favoured for its hydraulic quick setting qualities and displaying good compressive strength and resilience to the Irish climate. It has however introduced its own problems into Barryscourt, with a lack of permeability now which causes large scale condensation through most of the year and by allowing damaging salts to migrate into the surrounding stones and surface material. This mortar is a major contributing factor to Barryscourt's problems and this intervention proposition recommends an extensive overhaul of the mortar joints throughout the whole structures. It is proposed to remove as much of the 1996 restoration mortar as possible and to introduce a traditional lime based mortar of favourable and scientifically proven qualities which would be totally compatible with the original structure and help eliminate the damaging effects of moisture on the tower house. Fortunately, the overseeing organisation which cares for Barryscourt, the Office of Public Works, have changed to a safer and compatible natural hydraulic mortar (NHL 3.5), which is gauged with a pozzolan additive of purified kaolin, called Metastar.

In Barryscourt, it is advisable that a suitable mortar be researched to be entirely compatible with the limestone masonry units and the traditional original lime mortar in order to accurately and comprehensively confront the issue of moisture intrusion, as was the study conducted by Prof. Pavía on Ardamullivan castle in West Ireland (Pavía S. , 2005). Repointing with the present choice in place with the Office of Public Works (NHL 3.5 gauged with Metastar) is acceptable and would certainly be favourable over the previous restoration mortar presently in place throughout the majority of the castle.

Barryscourt Chimney Intervention:

The two main chimney stacks at Barryscourt have their own problems as they both exhibit internal damage, allow significant amounts of water to infiltrate the building and contribute to massive staining which occurs in the surrounding wall sections. The main chimney of the main block, which rises from the western side of the Great Chamber, is capped with a limestone slab. The slab appears to be sealed around the edges to the chimney stack itself, so most water must be kept out of the chimney at this point, depending on the quality of the sealing mortar. This more obvious contributing factor to the moisture infiltration down through the chimney is that the masonry joint mortar has degraded over the years and is now allowing large quantities to moisture to infiltrate down the shaft of the chimney. The chimney located at the northeast tower suffers from the same ingress, however, its capping limestone slab is not sealed to the chimney stack itself, thus allowing further moisture into the chimney interior and surrounding walls. Both chimneys require extensive repointing with a suitable repair lime mortar and both capping stones should be resealed from the frequent rain.

Rising Damp Intervention:

Barryscourt tower house has an obvious problem due to rising damp through the foundation walls and the lower sections of the ground floor rooms. This damage is described in detail in the inspection section of the thesis, with comprehensive staining and thermography evidence for the continued presence for moisture in the lower areas of Barryscourt's walls. This moisture presence has caused severe damage to the mortar joints and stone material of the external batter and has allowed the migration of harmful salts into the ground floor walls which were also observed during the visual inspection. Wetting and drying cycles during each year have caused surface damage and mortar loss. Solutions to this problem in everyday buildings can usually include the introduction of a damp proof course which can be inserted under the foundations walls, sealant injections into the foundations in attempt to retard moisture wicking or the introduction of ventilation tubes inserted at intervals throughout the wall. These solutions would be quite difficult to implement in Barryscourt's case, due to the dimensions of the castle foundations and support walls (2.75 metres thick in places). The exact dimensions of Barryscourt's foundations are unknown, due to the unavailability of excavation records at Barryscourt and the from the archaeology study conducted in the castle grounds in 1992 and 1994.

This intervention proposal proposes to introduce a ventilation channel around the external base wall of Barryscourt tower house. Since the walls and foundations are in direct contact with the surrounding ground, and taking into account the lack of a D.P.C. (damp proof course) or similar moisture barrier the walls are unable to dry to the outer environment. This constant presence of water moves up and down the wall in the wet dry cycles. If a free channel were introduced around the foundation walls, the internal moisture would be drawn out from the masonry and evacuated through evaporation.

The first step would be to hand-dig a series of trial holes adjacent to the castles foundations of approximately 1 metre square dimension and to a depth of 1 metres to give insight into the depth of the foundations and allow decisions on the determined depth for the ventilation channel. The more area of the foundation that is exposed to the ventilation channel, the more water that will be drawn out from the wall, provided the depth of the channel does not equal or exceed the depth of the foundations.

After the trial holes have been completed it is then possible to construct the channel alongside the foundation. A detailed cross section of the proposed intervention is shown in Figure 84 and the corresponding implementation procedure for the construction of the ventilation channel is as follows:

First a trench along the castle walls must be dug to a width of 3 metres back from the foundation face and to a depth of 1.3 metres down from the top of the foundation head. The face of the foundation wall must be cleaned and consolidated. Any damaged or degraded pointing must be carefully removed, the joint must be raked to a depth of twice its width and the joint should be replaced with the new restoration mortar as detailed before. The base of the trench must be consolidated and be laid with an impermeable layer of waterproofing membrane. A thin layer (0.1 metre) of C20 dry lean concrete should be laid over the waterproofing layer and compacted. Next, a concrete-block wall of 0.25 metre width and

1mtre depth should be constructed parallel with the foundation wall as the wall of the ventilation channel. Once this wall has been completed, the floor of the channel should be formed from a 0.2 metre layer of C30 wet concrete, and shaped to have a shallow concave shape with and an inclination to facilitate water drainage towards an outlet point which should be placed at the lowest point of the channel. This channel is then connected to an outlet connection through the concrete wall and out to the opposite side if the wall. Next capping pre-cast concrete slabs are laid across the top of the ventilation channel resting on the top of the foundation and concrete channel wall with a downward inclination away from the castle. An impermeable layer of waterproofing is laid across the concrete slabs and down against the outer face of the concrete ventilation wall with an excess projection of 1 metre from the wall itself and an excess projection of 0.3 metres from the castle wall facing. Next to the wall, a perforated drainage PVC pipe wrapped in permeable geotextile matting is laid as drainage for water which runs down the castle wall and over the ventilation channel (known as French drain). This pipe also collects any drained water from the ventilation channel via the outlet channel mentioned earlier and should be connected to the main storm water drainage system. The pipe is set in graded gravel from fine to course and is compacted for every 0.2 metres of gravel laid. The level of gravel is brought just shy of the concrete capping slab where it is topped with permeable geotextile matting. The gaps between the concrete capping slabs are grouted using an ordinary cement mortar and sealed. The surface gravel which covers the inner bawn area is then used to cover the pre-cast capping slabs and the channel is in operation (see Figure 83).

The highest (or most elevated) end of the ventilation channel should be fitted with an upright exhaust chimney to provide the necessary air movement through the channel, starting the drying process, whilst the lowest section is fitted to a sealed PVC pipe which is set into the ground and should run to an area of lower elevation (at least 1 metre lower than the exhaust level). By forcing a elevation differential and a sealed passageway, the air naturally moves through the channel beginning the “drawing process”. The first stage of the process will be passive; if the flow of air does not begin automatically, it should be induced using a connecting fan which would start the air flow (see Figure 83).

The channel is interrupted by one of the two minor adjoining walls which now corner off the west side of the castle. At these sections the channel should be extended 1.5 metres along this section of lesser wall but at a shallower depth (due to the smaller foundations). The size of the channel will be dependent on the established size of the smaller walls foundations. Where the bawn wall meets the tower house (at the main entrance on the southeast corner), the ordinary described channel can be continued around the wall to either side without interruption.

When set in place, this ventilation system should draw significant amounts of moisture from the castles foundation and help to restrict the damaging effects of wet-dry cycles on the lower walls of the tower house, help protect the batter wall which had been suffering due to water retention and hinder the transportation of soluble salts through the wall via capillary action. It is worth noting that this system would have been advised for inside the corresponding opposite side of the foundation walls at the interior regions also, but since the restoration project of the early 90's implanted an underfloor heating system, this section is off limits. However, even without an interior channel, the external ventilation channel would be expected to remove up to between 50% and 60% of the internal moisture of the castles lower walls and foundations. By protecting the lower regions of the structure and preventing damage, the system is effective and being hidden safely below the gravel of the bawn grounds, remains non-invasive to the original surroundings.

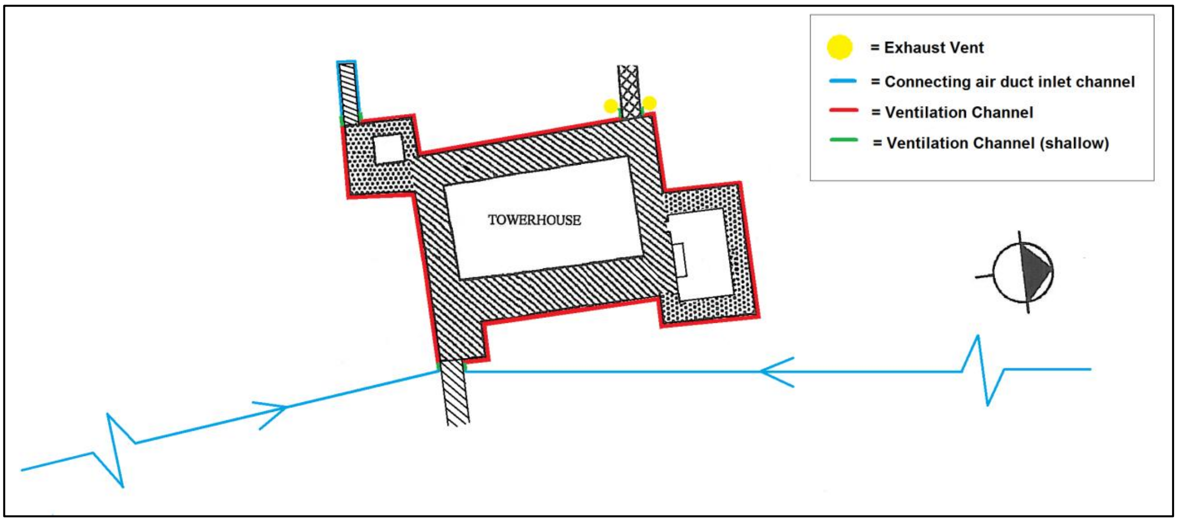


Figure 83: Ventilation channel layout plan view and inlet air channels

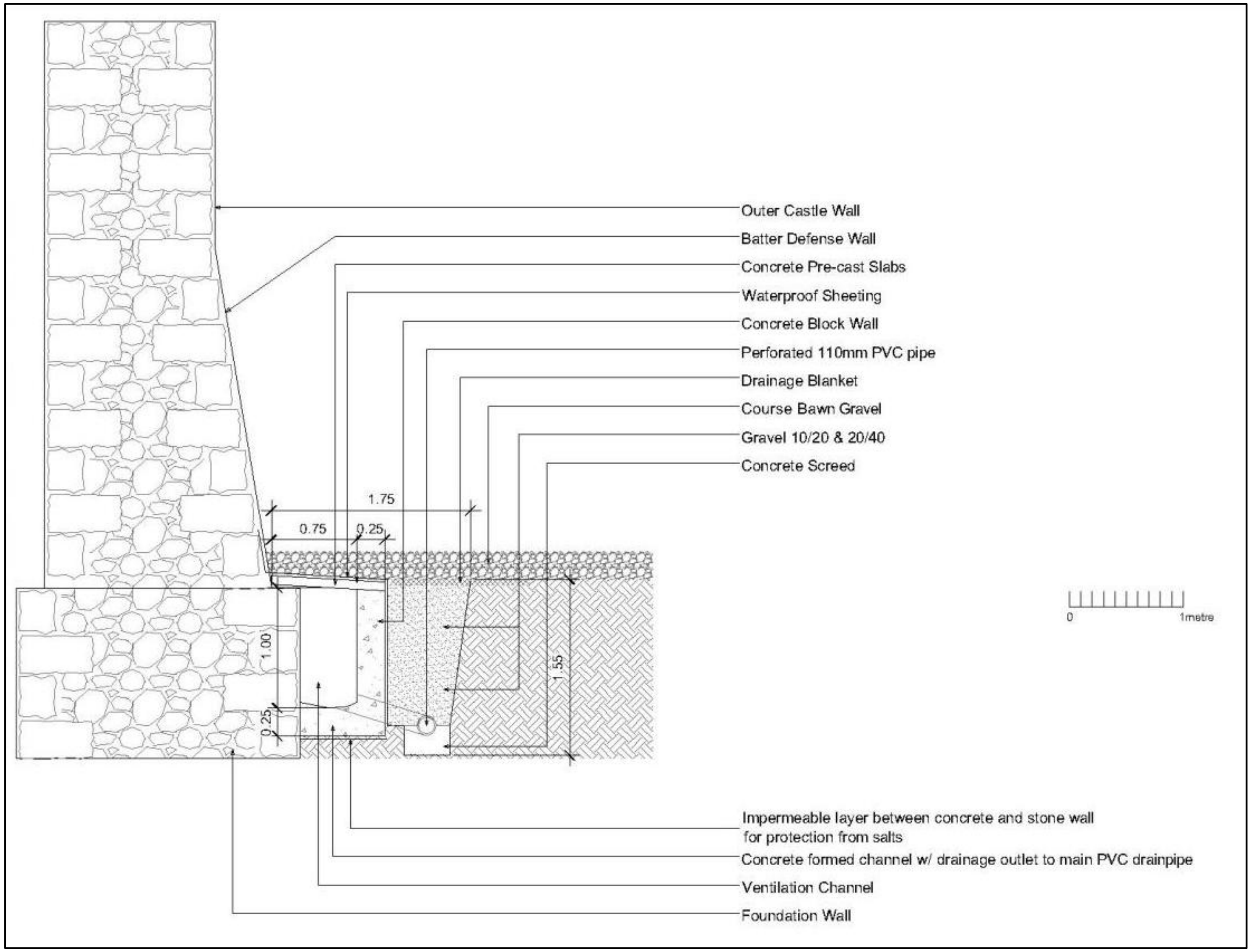


Figure 84: Detailed cross section of ventilation channel and design components

Proposal and Outline for Rendering of the Outer Walls of Barryscourt:

This final proposal suggests the reintroduction of a protective rendering plaster on the external walls of Barryscourt castle to ultimately impede moisture infiltration. This render cover all walls, including the chimney stacks and roof gables, with the exception of the window and door features. It is understood that this intervention is the most controversial and such an alteration to the buildings aesthetics is understandingly always met with criticism and scepticism. As outlined in the historical background, Irish tower houses and their stone and lime mortar masonry would have been finished with a protective sacrificial layer of lime based plaster mixed with organic material such as straw particles and animal hair, to retard the ingression of moisture through the buildings surfaces. This layer received the brunt of the Irish weather, forcing water to run down the surface of the wall and preventing the wind from driving water into the pores of the underlying porous lime mortar. The lime render would also been rejuvenated and reapplied every few years layer over layer. Due to the abandonment of the tower house, and the subsequent descent into ruin, the original render disintegrated and fell from the castle face, exposing the underlying masonry. The masonry was not designed to endure such a long term bombardment from the Irish weather, and this weathering, and later roof removal led to the accelerated decline of the building. Some small sections of the original protecting render can be still seen on parts of the northern face of the castle.

As outlined in the literature review section of this thesis, Ardamullivan castle in West Ireland benefited from the reintroduction of a protective rendering plaster on the external walls of the castle (see Figure 85). Ardamullivan castle was chosen due to the fact that moisture infiltration was threatening medieval plaster paintings on the castle interiors. The replica render used for the restoration project at Ardamullivan was based on a full scientific analysis of portions of the surviving original render layer. The main lime mortar was found to be of magnesium lime content, also displaying more favourable properties with regards porosity, capillarity and absorption. The resulting rendering plaster which was applied on the external walls has shown to be very effective in preventing moisture ingress and the project is a success.

Figure 85: Reintroduced protective render at Ardamullivan Castle, County Galway, Ireland (Searle, 2005)

The success at Ardamullivan beckons thoughts on the actual need for a protective render on Barryscourt. There are questions which require answering before an intervention is implemented. What is worth protecting in Barryscourt and how serious is the damage being caused to the structure itself? Does the damage inflicted warrant such a striking alteration to the buildings aesthetics? The reasons for and against can be outlined and summarised as follows:

Reasons Supporting the Application of an External Render:

- To protect the building from the moisture intrusion inflicted by the precipitous Irish climate. This is the fundamental point supporting the intervention. While the castle is not suffering structurally, it must be noted that the building was only restored approximately 15 years ago. The effect that the climate is having on the building is already plainly apparent and the building has been shown to be leaking from the roof, but most concerning, from the walls themselves. The lime masonry is not able to totally withstand the constant barrage of wind and rain and moisture works through the porous media into the internal environment causing large scale damage and decay. This decay can be certainly slowed by the replacement of the restoration mortar (as outlined in the previous intervention section) but it will not completely prevent moisture from reaching the interior, especially when subjected to long periods of rain and wind, which is the case of a significant portion of the year in Ireland. Moisture will still be absorbed following a repointing overhaul, albeit to a far less serious extent, yet after time, the continued weathering of the external surfaces and over years would begin the deterioration of the outer surfaces just as what happened after the building was abandoned. By reintroducing a protective render, the weathering of the internal masonry joints would be vastly reduced. In turn, the walls would have less water to release to the atmosphere during dry spells and hence, would prevent the growth of vegetation, moulds and fungi. The internal environment would not be moisture laden causing surface deterioration and the internal rooms and chambers would be far more hospitable all year round.

- The refurbishing project of the Barryscourt interior was conducted following the building conservation project of the late 90's. This project reconstructed furniture and everyday objects as used in a typical Irish tower house in medieval Ireland. These furnishings were painstakingly researched and crafted and lie in Barryscourt today as a reconstruction of the material culture in which an Old English family like the Barrys would have lived in during the buildings heyday. These furnishing are being subjected to harmful conditions due to the moisture presence in the interior of Barryscourt and have already shown indications of damage from moisture problems such as mould spots, staining and decay. It is important to protect these elements as part of the Barryscourt experience further encouraging an intervention to halt the water intrusion.

- It is important to understand that if the moisture infiltration at Barryscourt castle is not tackled soon then the problem will degrade into a state of severe damage quite soon since structural elements are showing beginning signs of decay already, such as the timber support beams. Prevention is always better than cure, and following this belief, rendering will help prevent further damage in the tower house and in effect, will be more cost effective. If the structure itself comes under serious threat, the cost implications could be far greater than introducing a renewable rendered plaster external surface. The rendering project undertaken at Ardamullivan castle has proved to be effective in the battle against moisture intrusion.

- Barryscourt castle is only open from the months of June to September every year. The main reasons for such a short span is due to the shortage of visitors during the other months and the costs associated with having responsible paid guides on site to give guided tours to visitors. Additionally, the conditions within the building during the winter and spring months are so inhospitable that visiting is not only uncomfortable, but also dangerous due to the abundant presence of moisture in the interior, including hazardous water on the stone steps of the staircases. By hindering water intrusion, conditions inside would be much more hospitable, safer and comfortable, and could encourage visitations from more visitors.

- The rendering intervention is a reversible intervention which complies with the ICOMOS charter guidelines (ICOMOS, 3.9, 2003).

Reasons opposing a rendering intervention at Barryscourt:

- Rendering of a castle façade can be sometimes quite controversial. The public grow an affinity for the naked limestone castle walls, appreciating the craftsmanship and the natural beauty of the stone which has been exposed for generations. To cover such a surface can sometimes be met with opposition regardless of the beneficial intentions of the conservation engineer/architect.

- The façade of a castle can be an open visual historical document of its existence and lifetime story. This is quite relevant to Barryscourt castle especially, since some damage documenting the castles presence in times of conflict and besiegement is still visible today. Cannonball impact damage is clearly visible on the east façade of the castle from artillery bombardment delivered by Oliver Cromwell's army. This interesting superficial damage is a surviving record of the castles history and would be hidden under a rendering plaster.

- A rendering surface has a limited lifespan; just as the original render fell off the building, a new rendered surface would weather over time and would need to be replenished/ renewed after a number of years. The frequency of renewal would only be quantifiable depending on the choice of render and the weather during that period. This signifies an on-going cost in the upkeep of the castle and any indefinite cost must be considered when raising the issue.

Decision and Recommendation:

The reasons for a rendering plaster to be reintroduced to Barryscourt, far outweigh the reasons against. Indeed, for such an intervention, sacrifices are made, yet reassurance can be offered that the intervention is entirely reversible without causing damage to the structure or its integrity. Furthermore, the entire building does not necessarily have to be completely covered; some sections which do not receive the brunt of the prevailing wind and rain, and which also exhibit features of historical importance, namely the cannonball damage, can be left exposed if desired. This thesis study has highlighted the damage and causes of Barryscourt's moisture problems. Interventions have been examined and outlined to suit this individual building giving the utmost concern to the integrity of the structure and under the guidelines set by the ICOMOS charter. The work should be additionally considered appropriate by a multidisciplinary project team in order to warrant action, in order to accurately meet the primary conservation goal – to assist in the conservation of the medieval building whilst protecting the historic fabric of the wall by using an authentic and sustainable repair material. These materials can be outlined and applied as follows:

Regarding which rendering materials should be used there are a number of solutions, the main point is to introduce materials which are entirely compatible with the existing masonry, any mortar in the newly pointed joints and any other component fabric.

Render 1:

Based on product analysis, the first rendering suggestion is based on the renowned render products produced by the building providers, MAPEI. The first layer (as outlined on the MAPEI website (MAPEI, 2007), MAPE-Antique Rinzaffo, is specially designed for historic buildings and works as a dehumidifying mortar which suits masonry which is subjected to moisture laden conditions, as a primary layer over rough masonry (porous stone or of lime nature) and wherever salt efflorescence are present – This product is designed to prevent soluble salts from penetrating macro-porous mortars. It is also suitable for structures damaged by the presence of chlorides and as a coat to improve bonding over rough surfaces. After the castles walls have been repointed as part of the previous intervention steps, the surface should be examined to ensure no large holes are gaps are present which would hinder the application of the render. Any large gaps should be filled out to make the surfaces flush, a technique known as “dubbing-out”, using small pieces of the identical stone to the masonry units and mortared in place using the restoration mortar. Following setting (roughly 3-4 days), the walls should be cleaned free of dust and loose particles. The wall should then be wetted until fully saturated prior to render application, ideally began on the day prior to application. Just before the first coat is applied, the wall should be re-wetted and saturated to prevent excessive “suction” of the moisture in the render. Whilst the wall is now saturated, the application is begun when the surface of the wall becomes dry. The mix is one bag (20 kg) to 5 – 5.5 litres of water, the addition of water should be carefully controlled until a semi fluid mix is achieved. The first layer should then be applied as a first coat with a thickness of approximately 5mm. After applying, the surface should not be smoothed with a float, in order to allow a keyed surface to which the next layer can grip easily, and also forming a chloride barrier.

After this first coat has been applied, it is time for a second coat, and new mix material. This material is called MAPE-Antique MC. This mortar is deemed as porous and vapour permeable as historic lime mortars while also showing scant affinity to rainwater, ideal for Barryscourt. MAPE-Antique MC is very durable and resistant to natural aggressions such as rain, rising damp, freeze thaw cycles, cracking due to plastic shrinkage, alkali-aggregate reaction and further resistance to sulphate salts (MAPEI, 2007). Before application, again the application surface is wetted until saturated and is then surface dried, either by air or by cloths. The mix is 1 bag (25 kg) to 3.5 litres of water; more water can be added to the mix if required but to a maximum of 4 litres. Layering of this coat should not exceed 3 centimetres per layer. Due to the moisture levels at Barryscourt, at least 2 layers of 3 centimetres would be recommended.

There are two remaining optional layers for decoration and protection. The next layer is a primer finishing layer which prepares the surface of the renders for a final decorative/protective coating. This primer rendering layer is called SILEXCOLOR Primer. This finishing rendering material is a modified potassium silicate mineral plaster that comes in paste form and is for interior or exterior "rustic" finishes. However, the MAPEI guidelines advise that this layer is not suitable for application on walls in direct sunlight or strong wind. It is also not advised to be used in locations where the humidity is over 85%. Having measured the humidity at Barryscourt, and observing the high levels, it is safe to say that these layers should only be used on the interior of the building if a rendering project was also decided upon for the interior walls.

A sketch of the layering of the different rendering plasters on a masonry wall is seen below in Figure 86.

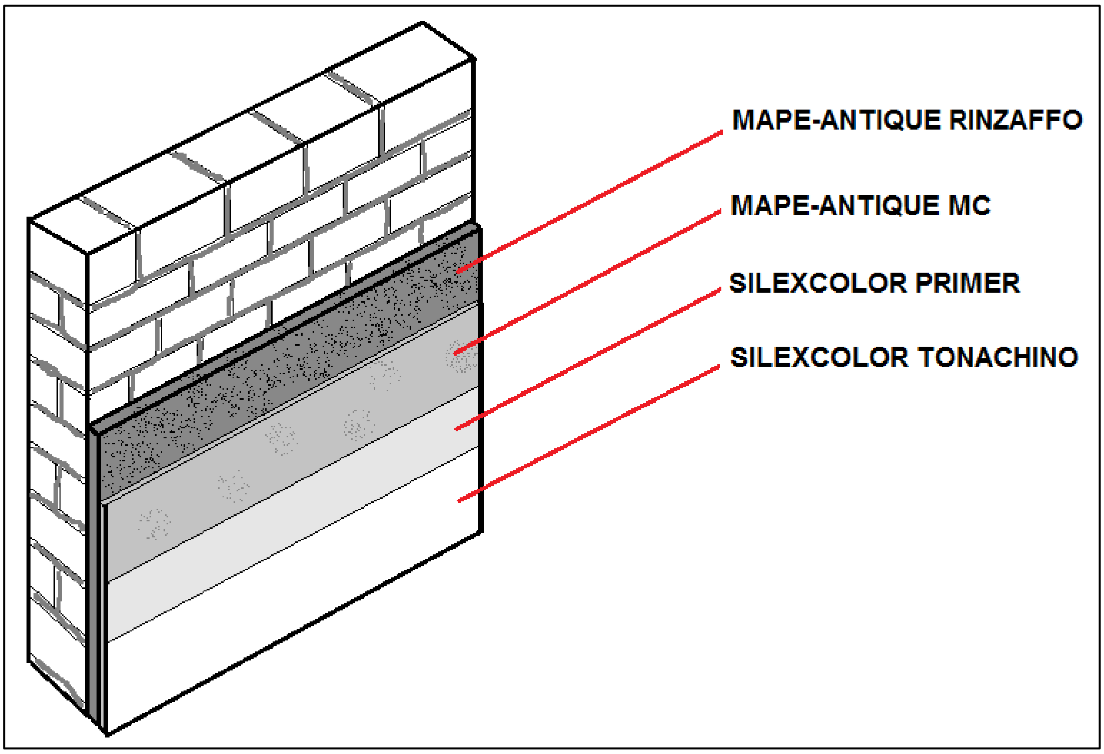


Figure 86: Suggested layering of MAPE antique renders on masonry surface at Barryscourt

Render 2:

The alternative suggestion for the rendering material is founded on the intuition gained from the various studies carried out on Ardamullivan castle by Professor Pavía, of Trinity College Dublin. These studies involved the identification of the exact materials and constituent mineralogy of the masonry units, the original mortar and the surviving render sections. By isolating the fundamental ingredients, it was then possible to develop and manufacture a suitable compatible rendering repointing and rendering mortar to suit the castle's needs and protect the structure in an efficient and harmonious manner. This study calls for a similar study to be conducted on the constituent materials at Barryscourt, to provide a similar, but unique, mortar mix for this unique situation. No two restoration projects are the same, and so, each require their own approach necessary to grasp the essence of the problem and to allow closer mortar matching, accurate judgement and intervention measures.

In addition to this, recent studies have shown that the addition of fatty materials (such as olive oil) to lime mortar mixes have reduced the mortars pore system to half (in percentage of volume) and decreased pore size. In addition to his finding, the study concluded that the addition of olive oil reduced the permeability of the mortars allowing them to perform much better than normal lime mortars in precipitous conditions. This research, if furthered, could have massive implications for a naturally improved mortar mix which could be suitable for the rainy climate in Ireland.

6.3.3 Intervention Proposals Discussion

As stated in the preliminary investigation, there is ample ventilation in Barryscourt castle due to the many exit shoots from the latrines and garderobes, through drainage spouts which are located under many of the main windows throughout the building, and the opening frames of the windows in main rooms. Therefore, ventilation is not a problem in the castle and further ventilation is not needed.

Heating is not an answer to moisture problems, in fact, by turning on and off the heating (as is done in Barryscourt), the heating causes more damage to the buildings material by subjecting the walls to rigorous drying, forcing the walls to lose moisture to the interior and drawing more moisture as a result. This was very evident during the Ross castle visit, which had a much more obvious and severe state of deterioration which would have been heavily influenced by the heating and cooling process. The heating in Barryscourt does little other than increase the interior air temperature which in turn reduces condensation in the surrounding environment, offering no solution to the buildings moisture problems.

Just as the moisture problem factors were described and outlined in previous chapters, the intervening countermeasures have been outlined in this chapter. They deal with tackling the problem at the sources, by interrupting the movement of water and the improvement of the existing original technologies to resist water intrusion. These intervention techniques would improve the climate, water resistance, aesthetics and safety of this historic building making it a more attractive attraction for visitors and as a cultural monument.

7 CONCLUSIONS

This thesis has comprehensively illustrated that Barryscourt does indeed suffer from moisture infiltration. Even after having an extensive structural overhaul as part of its 1990's restoration project, the castle continues to incur damage from water ingress. The study disassembled the problem by slowly addressing each section of the building, assessing the present condition, the type and severity of the damage in each location and the suspected origins of the affecting moisture.

The damage assessment prompted more thorough testing methods in order to identify key areas requiring attention, and the main sources of the moisture intrusion. The first non-destructive test procedure involved the thermography analysis. This test helped isolate sources of leaks in the master bedchamber by showing up new patches of "cold spots" in the upper corners of the room near the roof and wall connections. The thermography analysis successfully helped the author to identify that the roof was not working efficiently during times of rainfall and was leaking in several places.

Leading on from the thermovision analysis, the roof was inspected. Here, it was clear that due care and attention was not been given to the wall walk regions, and this neglect had allowed biological activity to gain a foothold. Additional to this, shoddy temporary sealing measures had shown to be allowing serious moisture intrusion down through the support walls causing the moisture influenced damage in the underlying structure.

Following the previous inspections and tests it was clear that the roof was not the only source of the buildings moisture. Patches of moisture presence and associated staining patterns were evident throughout the building. This led to thoughts that the masonry and particularly, the mortar, was soaking water from the external environment and wicking this moisture through the walls into the interior rooms and chambers. A water absorption test was conducted on all four façades of the external castle walls, and further tests were conducted on the interior limewashed walls of the first floor hall and the master bedchamber. The test results revealed the extensive absorption properties of the external and internal mortars, and illustrated how the building soaks up water during wet conditions. The moisture presence leads to a whole range of problems which were observed and described through the various inspections. Condensation and extensive evidence of salts on the interior walls indicated that water vapour was finding it difficult to escape from the building and that the restoration mortar was leaching damaging salts to the surrounding masonry, causing exfoliation and spalling of the surfaces.

Monitoring data-loggers which had been placed inside and outside the castle environment as part of this thesis study showed how the building behaved during a typical Irish summer month and conclusively illustrated how the building couldn't fully dry out during even the summer months due to the high internal and external humidity levels; the two were not different enough to allow significant moisture escape.

Finally, having established the key sources of infiltration and the most problematic regions, interventions were carefully devised to combat the water infiltration. An overhaul of the roof seals and guttering was advised, as was the total clean-up of all vegetation on the wall walks. Additionally, since the outer elevation walls are suffering from vegetation, this too will need to be taken care of. Due to the unfortunate cement gauged repointing mortar used in the restoration project and its damaging effects on the building, a full repointing overhaul with a traditional lime based mortar is recommended. The chimneys require attention since there is significant ingress through the top sections and the stacks themselves. Further repointing is recommended on the chimney stacks also.

The introduction of a ventilation channel was recommended for the rising damp problem which is also an issue in the lower section of Barryscourt. This channel would help draw moisture from the foundations and limit the water infiltration through the walls by capillary action. It would also prevent the wet/dry and crystallisation cycles of the salts in the lower wall.

Finally, a protective traditional lime based mortar was recommended and outlined for the whole building in order to seal the castle in a shielding “breathable” coating. This protective render, which has been shown to be effective in another tower house project in west Ireland, would help with Barryscourt moisture problems and allow the building to slowly dry out and recover whilst also improving its facilities and attractiveness to visitors.

Barryscourt is a spectacular monument of unquestionable historical importance and hence was chosen for a full restoration project less than twenty years ago. However, it has not escaped its main enemy; infiltrating moisture. It is important that this problem is confronted soon, before the damage consumes larger and affects more serious sections of the structure.

Irish buildings endure a constant battle with the climate and Irish tower houses are no different. This thesis has highlighted the problems suffered by these particular buildings and outlined methods to halt the moisture infiltration. Since tower houses are similar structures, in both construction and typology, enduring the same problems and climate, then the interventions devised in this study can therefore be applied to many other vulnerable tower houses in Ireland.

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ANNEX

Weather:

- European Weather Charts
- Total Monthly Rainfall Measurements – Cork Airport (1962-2010)
- Monthly Mean Temperature/Humidity Measurements - Cork Airport (1962 -2010)
- Mean Monthly Wind Speed Measurements - Cork Airport (1962-2010)

Damage Templates:

- As listed

Water Absorption Test Data:

- Water Test Tabulated Results
- Water Absorption / Relative Rate of Absorption Data Tables

Topography Survey of Barryscourt:

- As listed

- <u>European Weather Charts</u>

Chart 1: Number of days with precipitation amount >= 1 mm

Chart 2: Precipitation amount

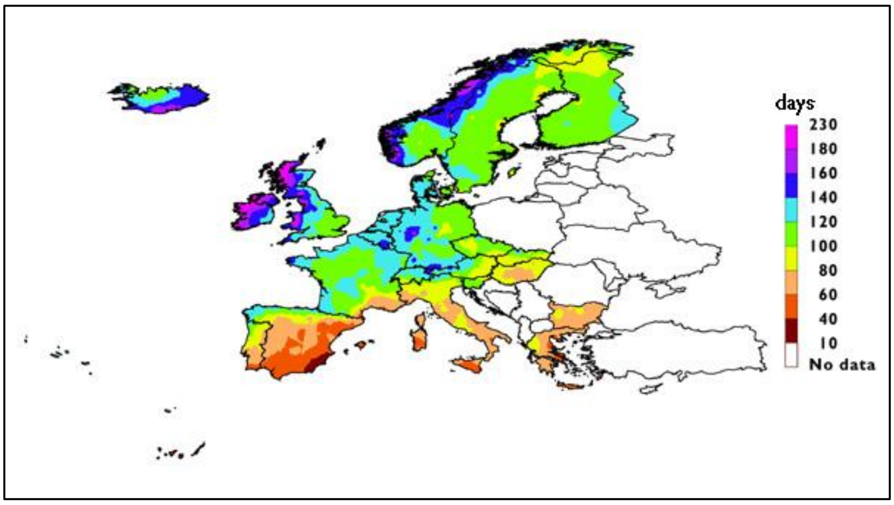
Chart 3: Number of days with Tn <= 0°C

Chart 4: Average mean temperature

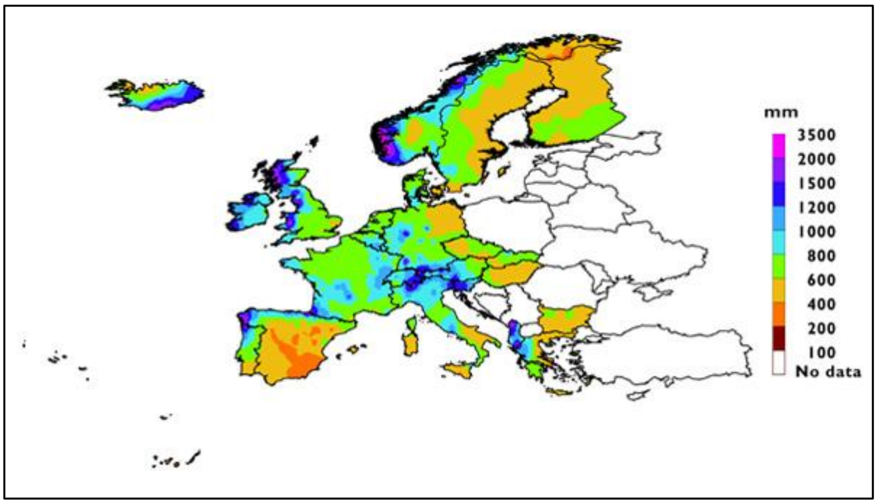
Chart 5: Average minimum temperature

Chart 6: Average maximum temperature

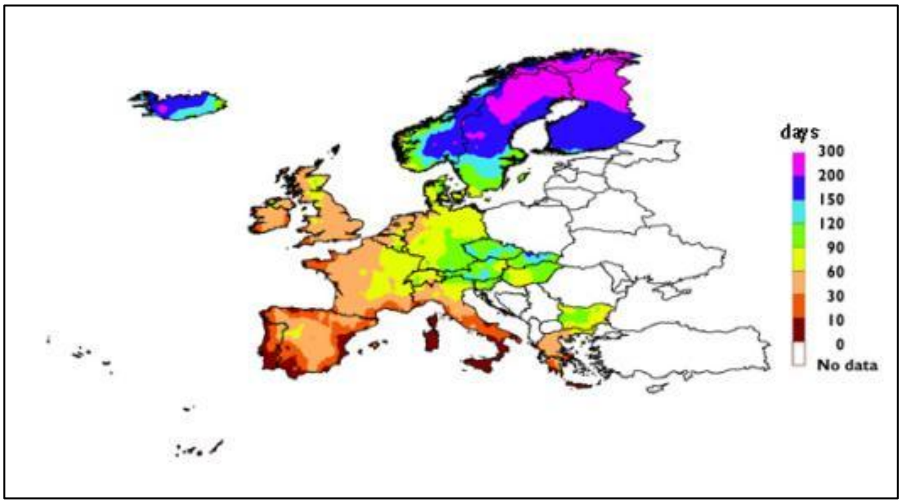
Chart 7: Duration of sunshine



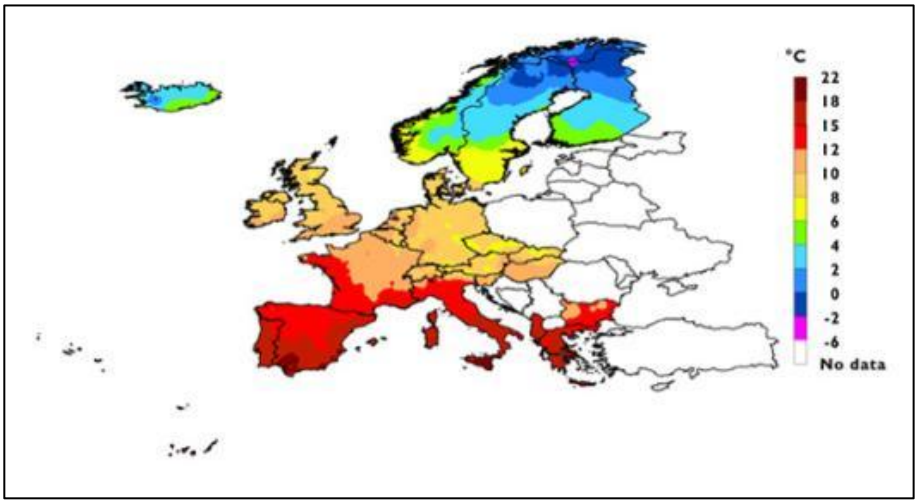
Number of days with precipitation amount >= 1 mm



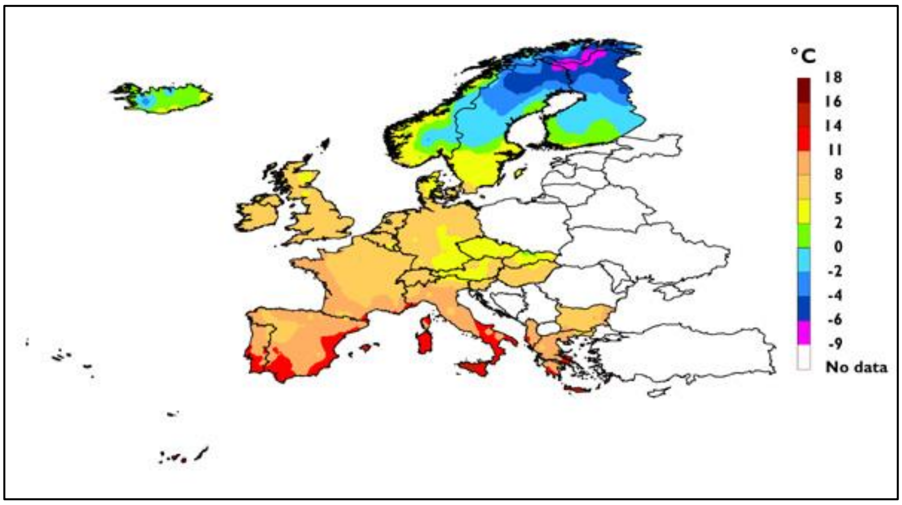
Precipitation amount



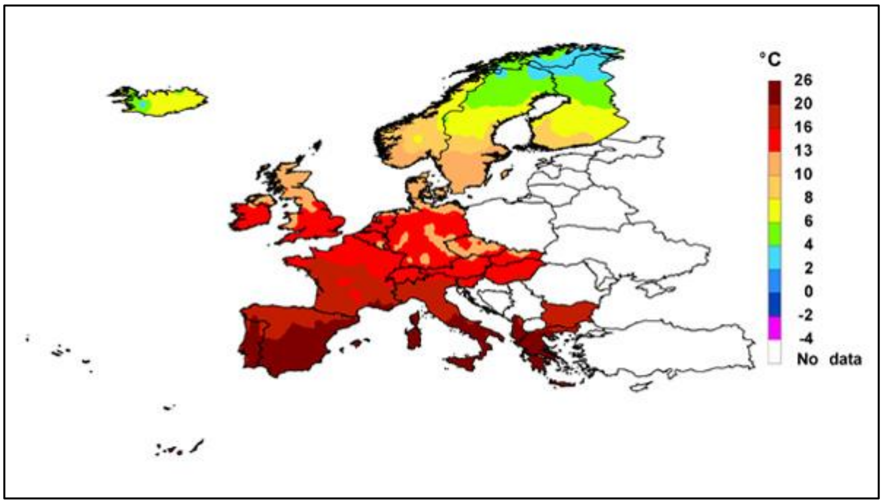
Number of days with Tn <= 0°C



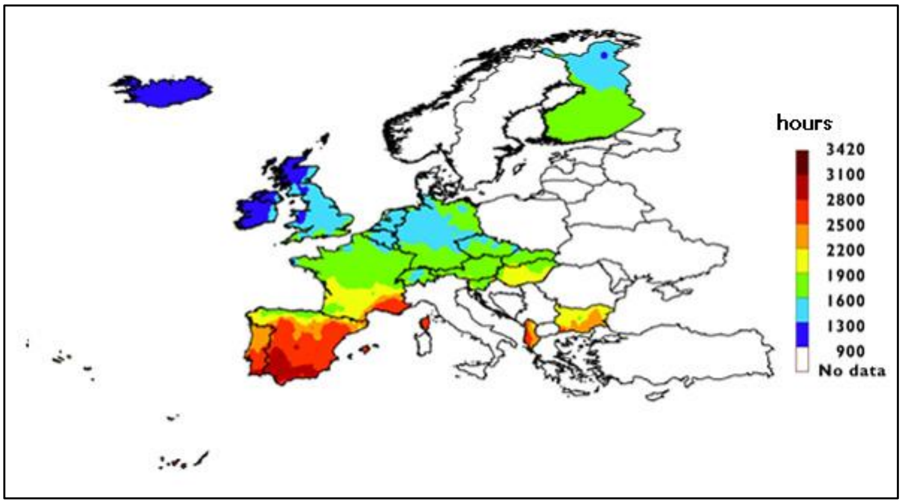
Average mean temperature



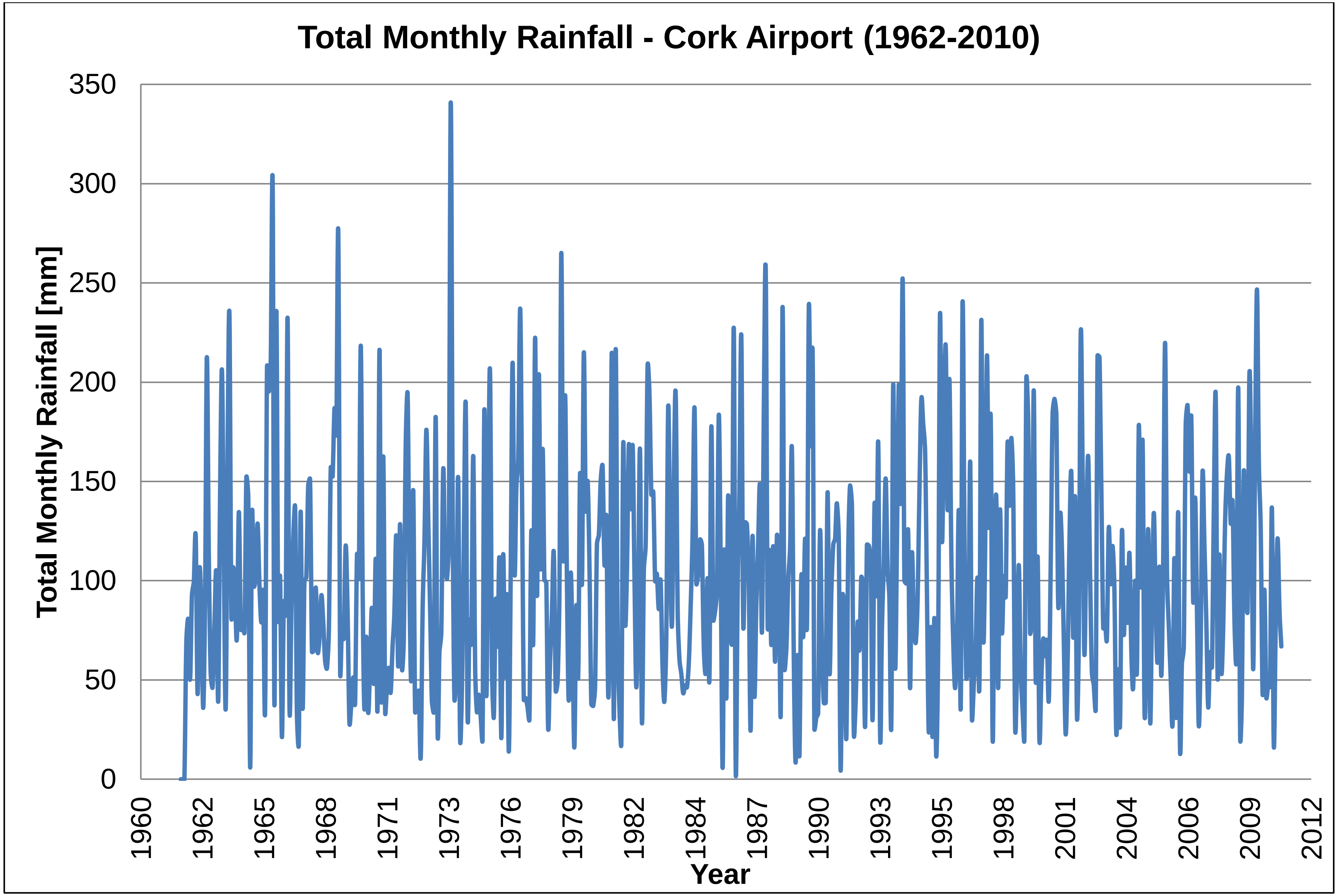
Average minimum temperature

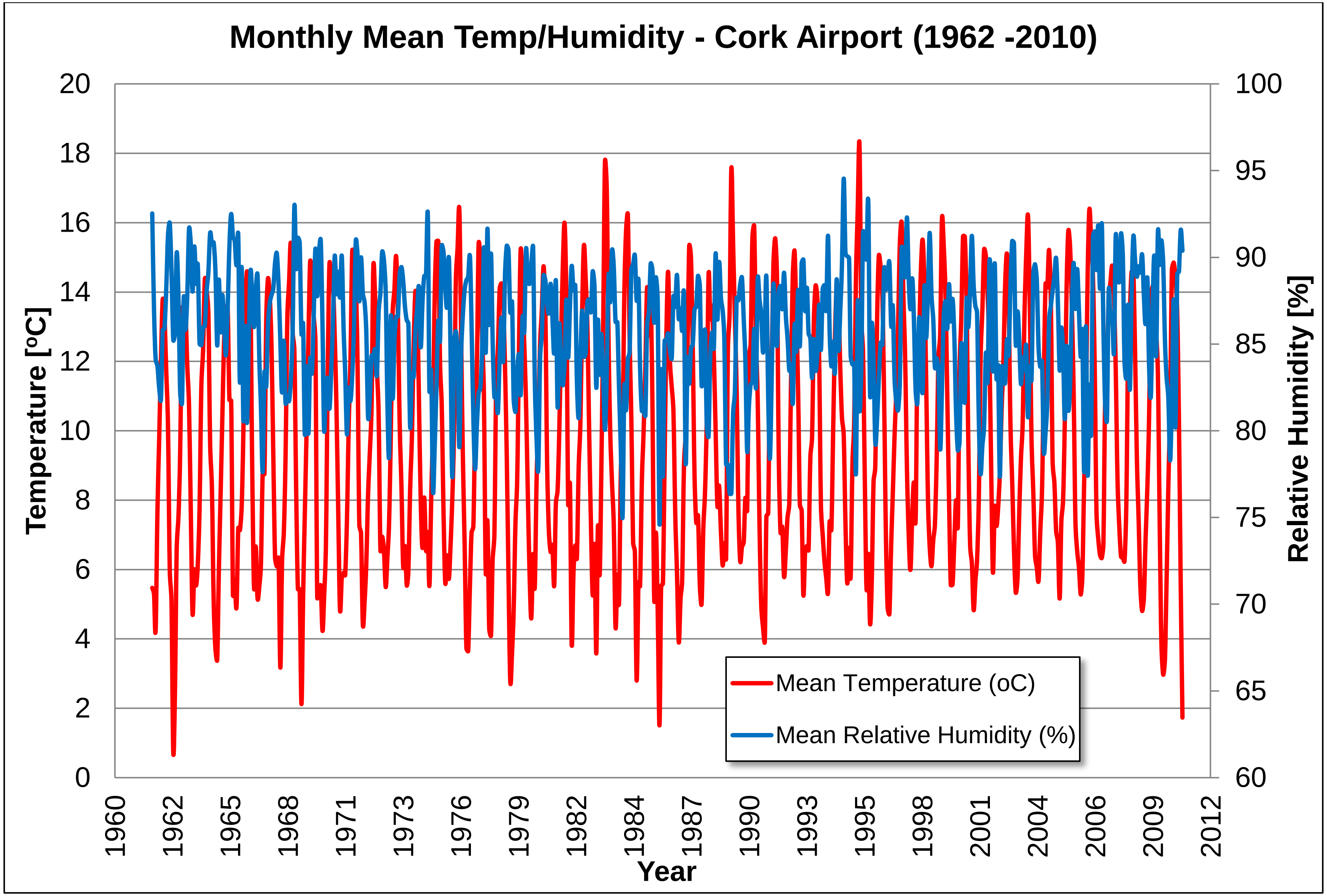


Average maximum temperature

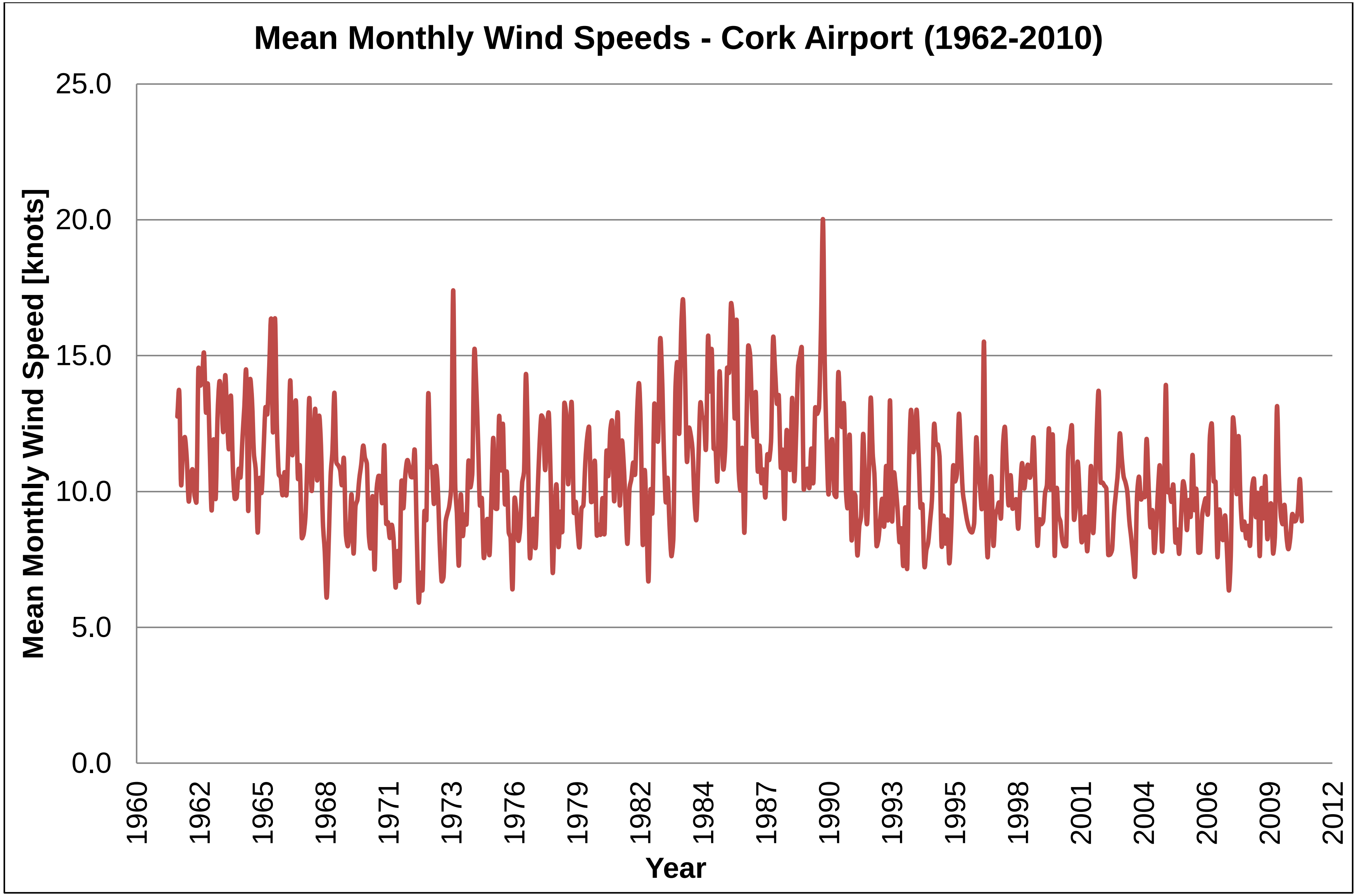


Duration of sunshine


Total Monthly Rainfall - Cork Airport (1962-2010)
Total Monthly Rainfall [mm]
0
50
100
150
200
250
300
350
1960
1962
1965
1968
1971
1973
1976
1979
1982
1984
1987
1990
1993
1995
1998
2001
2004
2006
2009
2012
Year



Monthly Mean Temp/Humidity - Cork Airport (1962 -2010)
Temperature [ºC]
Relative Humidity [%]
Year
20
18
16
14
12
10
8
6
4
2
0
100
95
90
85
80
75
70
65
60
1960
1962
1965
1968
1971
1973
1976
1979
1982
1984
1987
1990
1993
1995
1998
2001
2004
2006
2009
2012
Mean Temperature (oC)
Mean Relative Humidity (%)


Mean Monthly Wind Speeds - Cork Airport (1962-2010)
Mean Monthly Wind Speed [knots]
25.0
20.0
15.0
10.0
5.0
0.0
1960
1962
1965
1968
1971
1973
1976
1979
1982
1984
1987
1990
1993
1995
1998
2001
2004
2006
2009
2012
Year

CONDITION TEMPLATES

INDEX:

Exterior:

BIO_01 Biological activity - Vegetation growth (External Elevations Walls)
BIO_02 Biological activity - Vegetation growth (Roof Wall Walks and Drainage Regions)
BIO_03 Biological activity - Black staining due to lichens/moulds

CH_01 Chemical decay - Inadequate seals; Leaks due to silicone deterioration

PH_01 Physical decay - General weathering/Mortar loss

Interior:

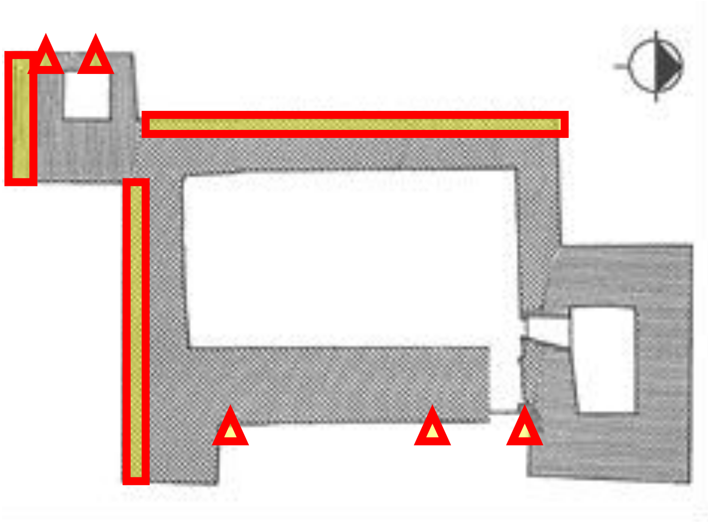
CH_02 Chemical decay - Efflorescence salts decay

BIO_04 Biological activity - Moulds/Fungi
BIO_05 Biological activity - Vegetation (Plants/Mosses)

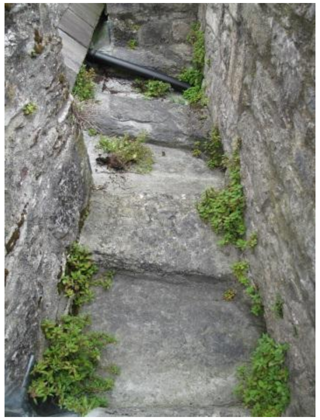
PH_02 Physical decay - Timber staining – Early stage decay
PH_03 Physical decay - Moisture induced staining and surface deterioration
PH_04 Physical decay - Moisture staining/dampness on ground floors

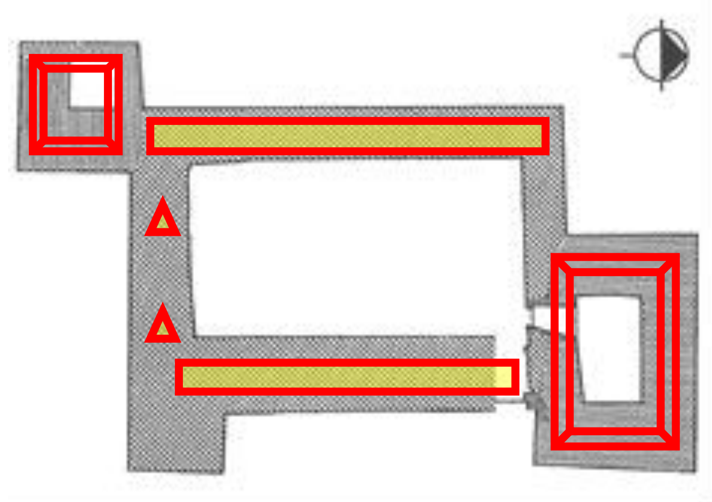
Barryscourt Tower House - Exterior		BIO_01
DAMAGE	Biological activity; Vegetation growth	Grading: Moderate
LOCATION	Exterior walls of castle, most predominant on south and western elevations.	
CAUSES	Ideal conditions for vegetation growth where mortar loss is evident; small cracks in mortar already present provide shelter and moisture encouraging mosses, fungi and more concerning plants. Areas exposed to the filtering of rain water, orientation and cracks benefit and encourage vegetation	
MAIN MECHANISM	Small size plants and mosses thrive in the cracks between stone and mortar. This growth causes further damage as roots weave into mortar and stone cracks expanding and forcing cracks to widen, allowing moisture into walls	
INTERVENTION PLAN	Removal of vegetation must be undertaken with great caution. The plants and ivies can be poisoned and cut out but caution must be taken when removing roots which have become woven into mortar and masonry – sometimes removing these roots and cause masonry to become unstable and cause further cracking. If roots are removed from joints then the void must be replaced with a suitable lime mortar as detailed in intervention chapter.	



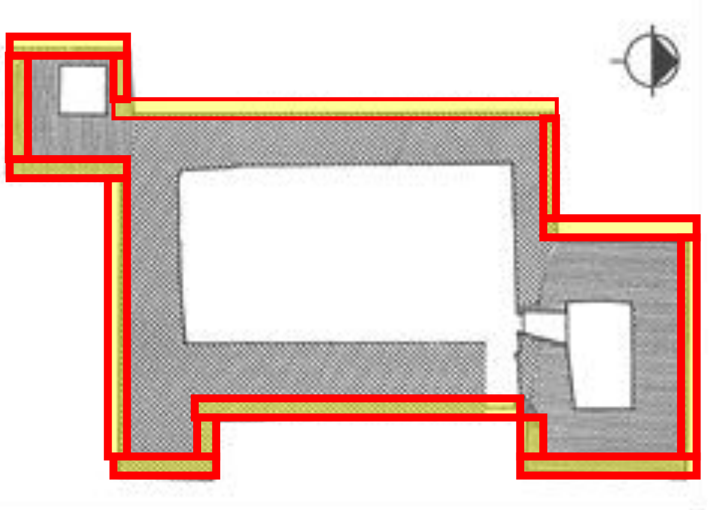


Barryscourt Tower House - Exterior		BIO_02
DAMAGE	Biological activity; Vegetation growth	Grading: Severe
LOCATION	Wall walks and roof sections where waterstones and saddles are situated. Gutters and downpipes also affected	
CAUSES	Ideal conditions for vegetation growth where water is remaining stationary on the roof surfaces. Small cracks in sealing mortar already present provide shelter and moisture encouraging mosses, fungi and more concerning plants, which in turn are rooting and allowing extra moisture in to underlying walls. Ample shelter and moisture under eaves and earthen debris ideal for growth. No maintenance of wall walk regions is in place.	
MAIN MECHANISM	Small size plants and mosses thrive in the cracks between stone and mortar. This growth causes further damage as roots weave into mortar and stone cracks expanding and forcing cracks to widen, allowing moisture into underlying walls	
INTERVENTION PLAN	Removal of vegetation must be undertaken with great caution. The plants and shrubs can be poisoned and cut out but caution must be taken when removing roots which have become woven into mortar and masonry – sometimes removing these roots and cause masonry to become unstable and cause further cracking. If roots are removed from joints then the void must be replaced with a suitable lime mortar as detailed in intervention chapter. Monthly maintenance attention must be adopted.	

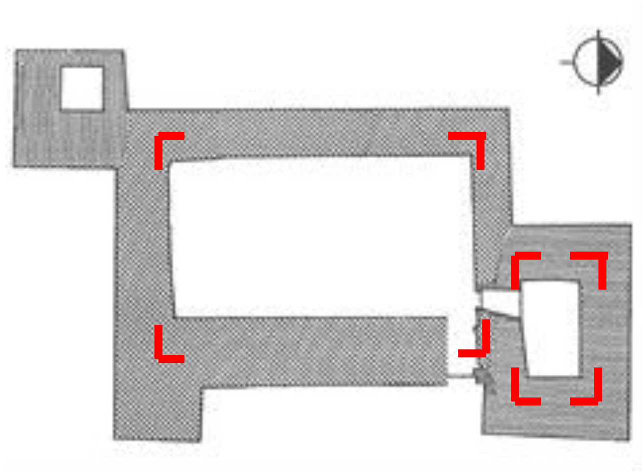




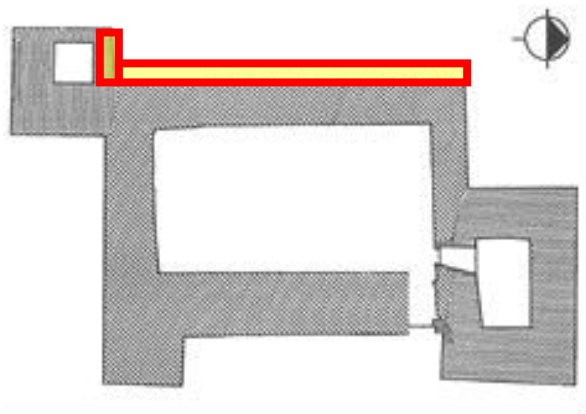
Barryscourt Tower House - Exterior		BIO_03
DAMAGE	Attack on stone/mortar due to biological growth; Black staining due to lichens/moulds	Grading: Non Serious
LOCATION	Tower House External Walls – All external façades are affected but east façade & north façade display large scale staining. The global staining occurs under dripstones and along batter wall	
CAUSES	Ireland's climate & the naturally occurring limestone's chemical composition give ideal conditions for the development for black lichens, seemingly in this case, *Placynthium nigrum*. Other patches of white lichens, perhaps of the Verrucariaceae species are also evident. Areas where water drips down wall from dripstones and sheltered façades provide ideal conditions.	
MAIN MECHANISM	Formation of black (and small patches of white) lichens affecting appearance and surface texture of stones	
INTERVENTION PLAN	To be absolutely certain of the lichen or fungi in question it would be advised to take a small sample and have it analysed by an expert. The staining does cover large areas of the castle façade and gives a dirty look to sections of the building. If an intervention plan for sealing the building was decided upon, in order to correctly and efficiently attach the new render to the surface of the castle, the lichen would first need to be removed. Removal is conducted by washing the surface using a mild anti-parasitic agent such as *dichlorophen* mixed with water, and scrubbed using nylon brushes.	



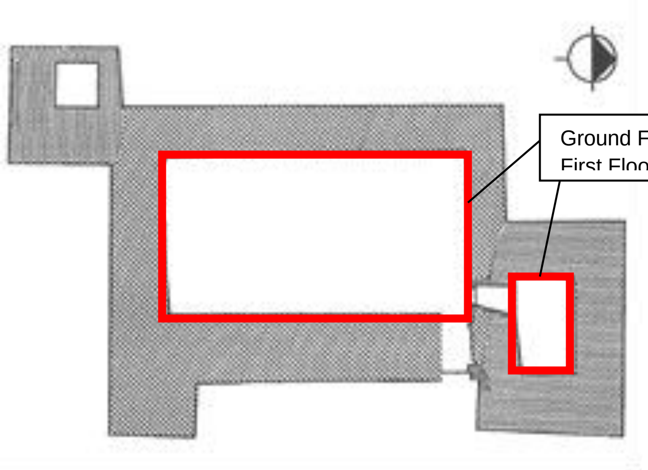
Barryscourt Tower House - Exterior		CH_01
DAMAGE	Inadequate seals – Leaks due to silicone deterioration	Grading: Severe/ Serious
LOCATION	On corner sections of northeast tower and main roof section (east side)	
CAUSES	Inadequate broken sealing of roof and flashing joints using silicone gel, Chemical degradation by UV light and weathering cause deterioration of silicone over time. No maintenance allowing situation to worsen and more moisture into underlying surfaces.	
MAIN MECHANISM	During times of rainfall/snow water percolates through gaps into walls and interior underneath causing massive damage. Silicone's relatively short life span and lack of compatibility with ancient structures and sealing techniques.	
INTERVENTION PLAN	Remove all silicone. Repair lead flashing and counter flashing to overlap in protected areas such as under first course of slate or under eaves. The mortar seals around the roof surface and the lead flashing must be replaced and improved with the lead being imbedded into the mortar forming a better seal. Regular inspections and maintenance should be implemented for caretaker.	



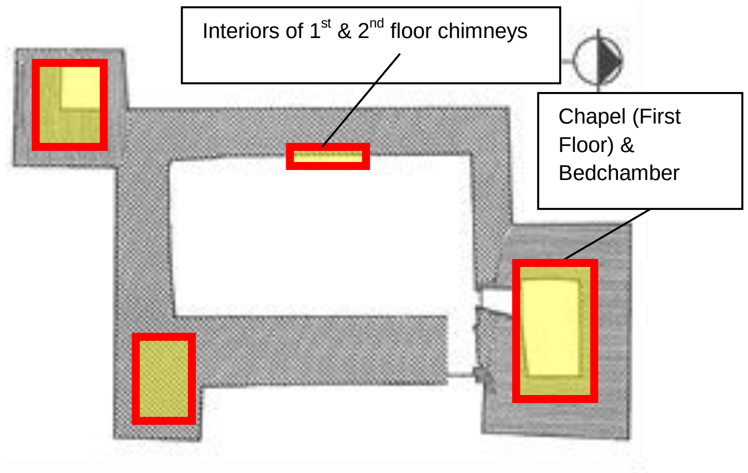
Barryscourt Tower House - Exterior		PH_01
DAMAGE	Physical decay; General weathering/Mortar loss	Grading: Severe/Moderate
LOCATION	Lower sections of the castles walls, most predominantly on the western façade especially on the batter wall section	
CAUSES	Cyclic weathering due to climatic conditions of rain and wind – absorptive mortar deteriorates over long periods of time. Rising damp due to lack of damp proofing under support walls – wall soaks moisture via capillary action. Greater accelerated damage in times of frost/ sub-zero conditions due to freeze thaw action that induces fatigue in stone and especially mortar.	
MAIN MECHANISM	Continued precipitous conditions weather the surface and infiltrate the pores of the permeable stone and mortar. Wetting and drying process induces stresses which over time cause fatigue and material loss (disintegration and spalling) in the stonework and mortared joints.	
INTERVENTION PLAN	First rising damp must be taken care of to some extent. Ventilation channel surrounding outer foundations can be introduced to draw moisture from the low lying walls (detailed in interventions chapter). Areas which are subjected to mortar loss must have joints raked and repointed with new lime based mortar. Walls should be additionally rendered with a lime render to assist water proofing.	



Barryscourt Tower House - Interior		CH_02
DAMAGE	Chemical attack; Efflorescence salts decay	Grading: Moderate
LOCATION	Evident during dry spells in ground floor main room, first floor halls and kitchen (most predominant near regions surrounding windows) but probably extends beyond these regions also. High humidity makes it difficult to pinpoint exact points of presence.	
CAUSES	Due to moisture presence in castle walls, soluble salts migrate from restoration mortars into surrounding masonry sections. The salt content may originate from the ordinary portland cement ingredient of the restoration mortar or from sand used in the mortar mix.	
MAIN MECHANISM	Salts become soluble in water and migrate through walls during wetting and drying. This cyclic crystallisation of the salts induce stress and eventual fatigue on the surface materials (named the limewash and surface mortar) causing eventual spalling, disintegration and mortar loss/surface exfoliation.	
INTERVENTION PLAN	Take samples of both mortar and stone and analyze in laboratory which exact salts are present. Removal of damaging mortar is not ideal since salts are already contained in the stone and these can migrate back into new mortar in the presence of moisture. By conducting laboratory tests, we can identify salts and devise counter measures to neutralize their effect. This can be done along with mortar removal and with the replacement with a lime based traditional mortar which has similar properties and appearance – (properties can be determined in lab tests – MDT, drill and analyze powder).	

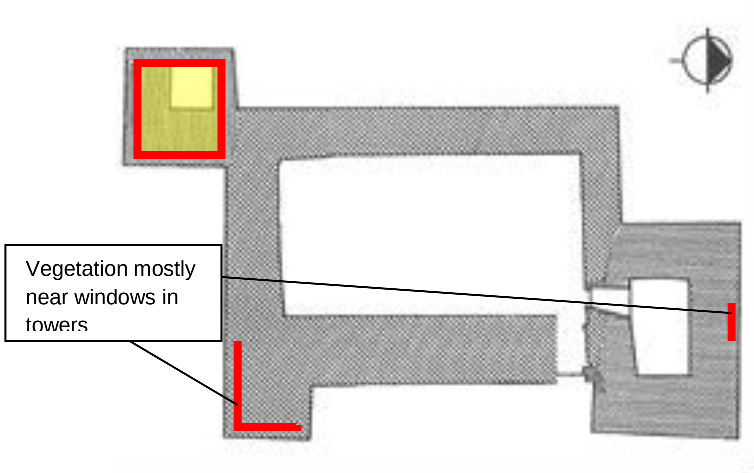


Barryscourt Tower House - Interior		BIO_04
DAMAGE	Biological Activity - Moulds/Fungi	Grading: Moderate
LOCATION	Master bedchamber most affected with large scale mould patterns and wall fungi on all walls, also surrounding chimney interior in bedroom and main chimney of Great Hall. Windows surrounds in all towers also exhibit activity. Chapel also badly affected but examination not conducted due to restricted access during ultra violet treatment.	
CAUSES	Abundant presence of moisture in the sheltered environment provides ideal conditions of biological activity, feeding from limewash organic content.	
MAIN MECHANISM	During the thermography analysis of the bedchamber, the roof was shown to be leaking in the corners of the room, especially where the bedroom chimney meets the roof. Water ingress is occurring and percolating through wall to provide necessary moisture for the moulds and fungi to flourish. Fungi spores attach to surface and multiply rapidly under correct conditions.	
INTERVENTION PLAN	Roof platforms and sealing must be radically improved with new guttering. Chimneys must be resealed and repointed (optionally rendering of outside), External walls would ideally be repointed and have a rendering plaster applied to somewhat deter moisture ingress. Interior walls would need to be washed with a mild water/bleach mix to kill spores of fungi, then re-limewashed after outer walls have been tended to.	

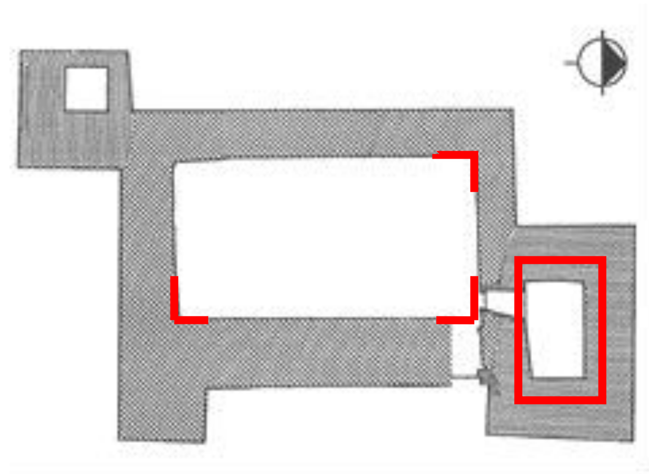


Barryscourt Tower House - Interior		BIO_05
DAMAGE	Biological Activity – Vegetation (Plants/Mosses)	Grading: Moderate
LOCATION	Southwest tower most affected with minor presence in southeast tower also (mostly inside window sections). Southwest tower has vegetation on ceilings, windows and floors.	
CAUSES	Vegetation works its roots into mortar joints causing damage such as mortar loss, degradation, cracking, disintegration of surface and constituents materials of walls and ceilings. Generate voids which allow further moisture and vegetation to take hold and flourish. Causes staining of surrounding areas when in contact with slow moving water. Very little/ no maintenance in effect, southwest tower is left unopened, section totally neglected because its closed to public.	
MAIN MECHANISM	Abundant presence of moisture in the sheltered environment provides ideal conditions of biological activity, feeding from limewash organic content.	
INTERVENTION PLAN	The plants/mosses can be poisoned and cut out but caution must be taken when removing roots which have become woven into mortar and masonry – sometimes removing these roots and cause masonry to become unstable and cause further cracking. If roots are removed from joints then the void must be replaced with a suitable lime mortar as detailed in intervention chapter. Source of moisture must be sealed/ removed with inspection of roof areas and window surrounds. Monthly maintenance attention must be adopted. Affected joints should be repointed with appropriate mortar (see interventions)	

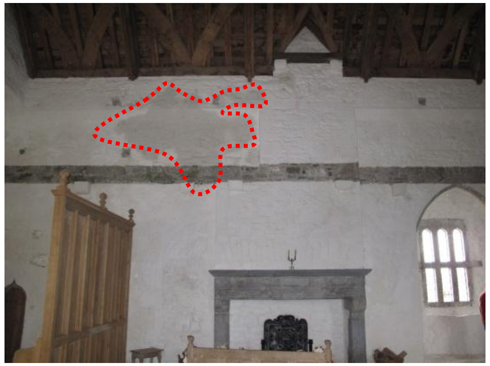


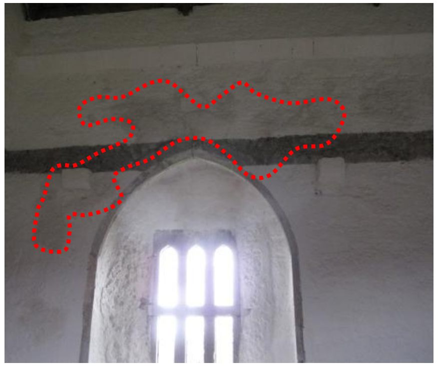


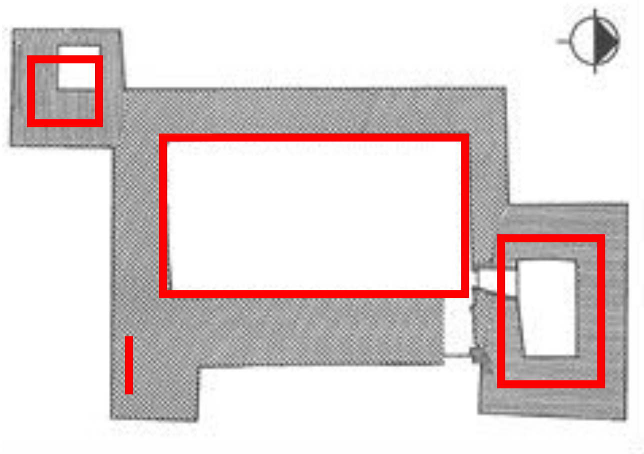
Barryscourt Tower House - Interior		PH_02
DAMAGE	Timber staining – early stage decay	Grading: Moderate
LOCATION	Staining on timber upper roof structure of main block of castle – believed to be from lack of covering/protection during rain storm during construction period. Lower corner sections show additional staining, suspected roof leakage. Master bedchamber with definite moisture damage in corners of timber roof where the support beams meet wall plate – especially near chimney and roof meeting point.	
CAUSES	Water infiltration through poor seals, or seals which have been broken due to vegetation roofs or deterioration of silicone filling. No existing guttering in place over master bedchamber allowing water time to remain on roof surface and infiltrate mortar.	
MAIN MECHANISM	Over time and due to lack of maintenance, vegetation has taken hold and opened seals in lead and mortar joints allowing water to percolate down onto wall plate and into interior walls. Timber elements soak water via capillary action and retain moisture causing staining, and in extended periods of time, rotting and deterioration of structural ability.	
INTERVENTION PLAN	Since the roof is the main source of the damaging moisture, guttering must be tended to, or introduced in areas where it doesn't exist. Mortar sealing joints of waterstones and saddles must be freed from vegetation and repointed. Lead flashing must be investigated by a trained roof technician and countered to avoid dripping inside the roof sections. All traces of silicone should be removed and seal should be woven into mortar joint or ran up under slating to rule out infiltration.	

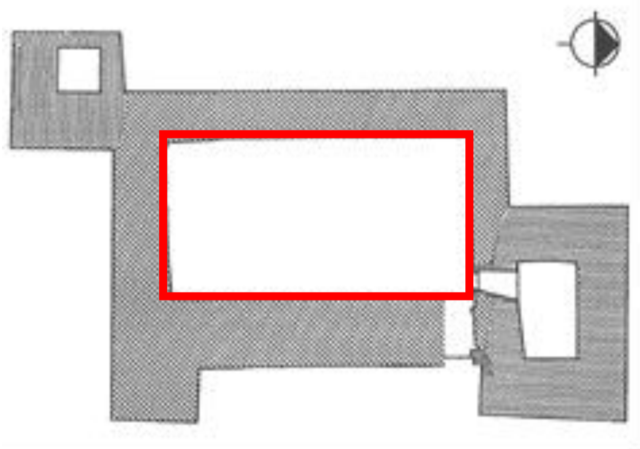


Barryscourt Tower House - Interior		PH_03
DAMAGE	Moisture induced staining and surface deterioration	Grading: Moderate
LOCATION	Global problem occurring on most interior walls of the tower house, especially noticeable in first floor hall, Great Chamber hall walls, northeast tower rooms exhibit many staining patches.	
CAUSES	Moisture causing staining - Number of contribution factors including faulty roof sealing joints, inadequate drainage. However, the moisture staining patches also occur in the middle of walls signifying porous masonry which is facilitating the ingress of moisture in times of rain and accelerating when accompanied by driving wind.	
MAIN MECHANISM	Water works through wall by differential pressure force and infiltrates to interior facades where it stays, causing staining of materials, namely lime wash and mortar joints, stone facing and timber. Constant moisture causes limewash to discolour to cream/yellow. Water combines with tannins in timber and stains walls when dripping or pouring. Water leaves staining lines and watermarks on naked stone.	
INTERVENTION PLAN	Roof sections should be repaired/ maintained. (See last template for intervention). Walls of castle should be repointed to repair mortar joints which are allowing moisture through. Rendering external plaster should be ideally reapplied using lime render to improve waterproofing whilst still allowing the walls to breathe in times of dry weather. Ventilation should be maximised to aerate the building during these times also and further the drying process.	







Barryscourt Tower House - Interior		PH_04
DAMAGE	Moisture staining/dampness on ground floors	Grading: Non Serious
LOCATION	Ground floor flagstones and lower sections of ground floor walls	
CAUSES	Rising damp originating from surrounding walls – extensive moisture presence for long periods of time causes staining and damage to wall surfaces especially in lower sections. Semi-impermeable flooring due to cement content in mortar surrounding floor flagstones.	
MAIN MECHANISM	Water rises through stones and mortar or foundations and load bearing support walls via capillary action. Water remains in periods of prolonged rain, causing staining. Wetting and drying of mortar and surface materials induces forces on materials who over extended periods, become fatigued and disintegrate/spall leading to mortar loss and surface damage. Water cannot evaporate through flooring also due to suspected use of ordinary portland cement in flooring mortar surrounding flagstones.	
INTERVENTION PLAN	External ventilation channel surrounding outer foundations can be introduced to draw moisture from the low lying walls (detailed in interventions chapter). Floor paving must be analysed for composition – if ordinary portland cement was used in the mix, then the floor must be re-laid with a more permeable flooring mortar around flagstones to allow moisture vapour to escape and facilitate drying.	
		

Water Absorption Tabulated Test Results

	Accumulated Volume [mL]										
Time [mins]	*Test 1*	*Test 2*	*Test 3*	*Test 4*	*Test 5*	*Test 6*	*Test 7*	*Test 8*	*Test 9*	*Test 10*	*Test 11*
00	0	0	0	0	0	0	0	0.00	0.00	0.00	0.00
05	0.2	2.5	2.6	0.2	0.2	0.65	0.3	1.15	0.45	0.75	1.20
10	0.25	3.9	3.6	0.4	0.3	1.2	0.6	2.00	0.65	1.10	1.80
20	0.35	7.3	6	0.5	0.6	2.3	1.2	3.20	1.15	1.75	3.15
26		12.3									
30	0.4		7.8	0.7	0.9	3.25	1.6	4.30	1.60	2.35	4.10
45								5.00	2.20	3.15	5.80
60	0.5			1	1.55	6	2.5			3.85	

External Test	
Internal Test	

Test 1 – Naked Stone (South Wall)
Test 2 – Mortar A (South Wall)
Test 3 – Mortar B (South Wall)
Test 4 – Mortar (West Wall)
Test 5 – Mortar (North Wall)
Test 6 – Mortar A (East Wall)
Test 7 – Mortar B (East Wall)
Test 8 – Limewashed Mortar (First Floor – West Wall)
Test 9 – Limewashed Stone (First Floor – East Wall)
Test 10 – Limewashed Original Plaster (Bedchamber South Wall)
Test 11 – Limewashed Mortar (Bedchamber Latrine – West Wall)

Absorption Tabulated Test Results

External Walls:

Test Number: 1
Tested Material: Naked Limestone
Location: South Facing Wall

Time [mins]	Acc. Vol. [mL]	Rel. Vol. [mL]	Water Absorption Rate [mL/min]	Rel. Water Absorption Rate
0	0	--	--	--
05	0.2	0.20	0.04	1.0
10	0.25	0.05	0.01	0.3
20	0.35	0.10	0.01	0.3
30	0.4	0.05	0.01	0.1
60	0.5	0.10	0.00	0.1

Test Number: 2
Tested Material: Mortar A
Location: South Facing Wall

Time [mins]	Acc. Vol. [mL]	Rel. Vol. [mL]	Water Absorption Rate [mL/min]	Rel. Water Absorption Rate
0	0	--	--	--
05	2.5	2.5	0.5	1.0
10	3.9	1.4	0.28	0.6
20	7.3	3.4	0.34	0.7
26	12.3	5.0	0.83	1.7
Leaked				

Test Number: 3
Tested Material: Mortar B
Location: South Facing Wall

Time [mins]	Acc. Vol. [mL]	Rel. Vol. [mL]	Water Absorption Rate [mL/min]	Rel. Water Absorption Rate
0	0	--	--	--
05	2.6	2.6	0.52	1.0
10	3.6	1.0	0.20	0.4
20	6	2.4	0.24	0.5
30	7.8	1.8	0.18	0.3
60	--			

Test Number: 4
Tested Material: Mortar
Location: West Facing Wall

Time [mins]	Acc. Vol. [mL]	Rel. Vol. [mL]	Water Absorption Rate [mL/min]	Rel. Water Absorption Rate
0	0	--	--	--
05	0.2	0.2	0.04	1.0
10	0.4	0.2	0.04	1.0
20	0.5	0.1	0.01	0.3
30	0.7	0.2	0.02	0.5
60	1.0	0.3	0.01	0.3

Test Number: 5
Tested Material: Mortar
Location: North Facing Wall

Time [mins]	Acc. Vol. [mL]	Rel. Vol. [mL]	Water Absorption Rate [mL/min]	Rel. Water Absorption Rate
0	0	--	--	--
05	0.2	0.2	0.04	1.0
10	0.3	0.1	0.02	0.5
20	0.6	0.3	0.03	0.8
30	0.9	0.3	0.03	0.8
60	1.55	0.65	0.02	0.5

Test Number: 6
Tested Material: Mortar A
Location: East Facing Wall

Time [mins]	Acc. Vol. [mL]	Rel. Vol. [mL]	Water Absorption Rate [mL/min]	Rel. Water Absorption Rate
0	0	--	--	--
05	0.65	0.65	0.13	1.0
10	1.2	0.55	0.11	0.8
20	2.3	1.10	0.11	0.8
30	3.25	0.95	0.10	0.7
60	6	2.75	0.09	0.7

Test Number: 7
Tested Material: Mortar B
Location: East Facing Wall

Time [mins]	Acc. Vol. [mL]	Rel. Vol. [mL]	Water Absorption Rate [mL/min]	Rel. Water Absorption Rate
0	0	--	--	--
05	0.3	0.3	0.06	1.0
10	0.6	0.3	0.06	1.0
20	1.2	0.6	0.06	1.0
30	1.6	0.4	0.04	0.7
60	2.5	0.9	0.03	0.5

<u>Internal Wall Tests:</u>

Test Number: 8
Tested Material: Limewashed Mortar
Location: First Floor - West Facing Wall

Time [mins]	Acc. Vol. [mL]	Rel. Vol. [mL]	Water Absorption Rate [mL/min]	Rel. Water Absorption Rate
0	0	--	--	--
05	1.15	1.15	0.23	1.0
10	2	0.85	0.17	0.7
20	3.2	1.20	0.12	0.5
30	4.3	1.10	0.11	0.5
45	5	0.70	0.05	0.2

Test Number: 9
Tested Material: Limewashed Stone
Location: First Floor - East Facing Wall

Time [mins]	Acc. Vol. [mL]	Rel. Vol. [mL]	Water Absorption Rate [mL/min]	Rel. Water Absorption Rate
0	0	--	--	--
05	0.45	0.45	0.09	1.0
10	0.65	0.20	0.04	0.4
20	1.15	0.50	0.05	0.6
30	1.6	0.45	0.05	0.5
45	2.2	0.60	0.04	0.4

Test Number: 10
Tested Material: Limewashed Original Plaster
Location: Bedchamber – South Facing Wall

Time [mins]	Acc. Vol. [mL]	Rel. Vol. [mL]	Water Absorption Rate [mL/min]	Rel. Water Absorption Rate
0	0	--	--	--
05	0.75	0.75	0.15	1.0
10	1.1	0.35	0.07	0.5
20	1.75	0.65	0.07	0.4
30	2.35	0.60	0.06	0.4
45	3.15	0.80	0.05	0.4
60	3.85	0.70	0.05	0.3

Test Number: 11
Tested Material: Limewashed Mortar
Location: Bedchamber Latrine – West Facing Wall

Time [mins]	Acc. Vol. [mL]	Rel. Vol. [mL]	Water Absorption Rate [mL/min]	Rel. Water Absorption Rate
0	0	--	--	--
05	1.2	1.2	0.24	1.0
10	1.8	0.6	0.12	0.5
20	3.15	1.35	0.14	0.6
30	4.1	0.95	0.09	0.4
45	5.8	1.70	0.11	0.5

Topography Survey of Barryscourt – (OPW Archives 2011)