EEP13/9/10

IGC 5 TASK GROUP REPORT

BUILDING CONDITIONING OF LIGHTHOUSES, ACCOMMODATION, OUTBUILDINGS AND ASSOCIATED STRUCTURES

2009

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Cover Page: Storm Lashed Longships Lighthouse, photograph courtesy of Tim Stevens (2008)

FOREWARD

This report is based on the document jointly produced in 1992 by Mr P. Hyde (Trinity House Lighthouse Service), Mr R. Kinnear (Northern Lighthouse Board) and Mr M. Taylor (Commissioners of Irish Lights) entitled '*Humidity Condensation and Conditioning of Lighthouse Buildings for Unattended Operation*'.

Their report provided information on the nature of atmospheric humidity, the factors that control condensation, the impact of condensation on building fabric and methods of minimising the adverse effects of condensation in unattended buildings.

Sixteen years have elapsed since the release of that report and in that time much additional information and data have been gathered to improve understanding of the management of external and internal building conditioning. Also during that time there has been a shift towards greater reliance on renewable energy sources for building conditioning with an often associated change in internal conditioning regimes. Unfortunately, in the last sixteen years the difficulties of maintaining the condition of automated structures exposed to maritime environmental conditions has become an evermore significant issue in terms of both financial demand and expertise as the cumulative effects of inadequate building conditioning become increasingly evident.

In response, the IGC5 Task Group on 'Building Conditioning' has undertaken the updating of the original report with this new document aiming to build on the earlier 1992 report through the inclusion of additional data sets and advice on methods of remotely controlling building condition in the context of an increased reliance on renewable energy sources and changing building usage. It should be noted that much of the text from the original report has been included, often in paraphrased form, in this updated report with additional material on building conditioning case studies and power generation systems taken from (Blakeley 2006*).

IGC5 Task Group

2008

*Blakeley, R.J. 2006. *Conditioning of Remote Historic Lighthouses and Associated Buildings: The Role of Renewable Energy Systems.* Unpublished MSc Dissertation, Heriot-Watt University, Edinburgh.

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INTRODUCTION

The key to successful internal building condition is good maintenance of the external structure coupled with a sound understanding of the role and control of environmental factors such as relative humidity, temperature and salt availability.

Prior to automation, maintenance of internal and external condition was achieved through the daily actions of keepers who ensured good ventilation of structures and up-keep of the structural fabric. Any problems were promptly dealt with and/or reported creating a regime whereby building conditioning was guaranteed through a proactive process of relatively minor daily maintenance actions and occasional major works when required. In recent decades, automation and the associated de-manning of stations had several major implications for the long-term condition of buildings.

First, and probably most importantly, is the change from proactive management to a more reactive regime characterised by intermittent maintenance visits. Unfortunately this has resulted in the accumulation of initially minor issues of up-keep which, when not promptly addressed, develop into more substantial and costly problems.

Secondly, the automated stations have, in most instances, experienced a significant change in their internal environmental conditions. This change is manifest in a shift from conditions characterised by efficient, regular ventilation to those dominated by 'static air' where poor regulation of atmospheric humidity combined with the lack of adequate air movement has facilitated the development of condensation.

Finally, with the departure of permanently resident personnel, heating regimes changed with, in most cases, a significant reduction in the amount of heating in buildings and an associated increase in reports of pervasive dampness and visible condensation.

Under such major regime change, good maintenance, regular inspections, building data monitoring and active building conditioning are essential if the future integrity of these historic and, often architecturally significant, structures is to be ensured. Automation, de-manning and restructuring of the General Lighthouse Authorities (GLAs) has by necessity required a major change in the asset management ethos. In this post-automation era, characterised by budgetary restrictions, increased public accountability, new technologies and personnel reduction within the GLAs, building conditioning often requires compromise between an ideal level of intervention and what can realistically be achieved. Consequently, compromise is essential in building condition management with a resultant shift in emphasis from maintaining all stations to the best possible standard to a situation where 'acceptable' condition standards are determined by the operational status of the station. This more pragmatic approach to condition management reflects the influence of several factors:

- **Financial constraints** – it is not financially possible to maintain all stations to an 'ideal' standard of condition so spending has to be prioritised and targeted. The drive to reduce costs by removing the keepers during the 1970s and 1980s resulted in the engineering emphasis being placed primarily on the replacement and maintenance of Navigational Aids with comparatively less spent on building conditioning. The effect of this was a decline in the general quality of internal environmental conditions of lighthouses, which was gradually made manifest during the 1990s through deterioration of the internal fabric. In response, building conditioning has gradually assumed much greater significance in long-term maintenance programmes.

- **Access** – given the remote character of stations, particularly the numerous off-shore sites, station access has to be planned in advance including co-ordination of specialist contractors, local boats and ship and helicopter deliveries. In addition, access may be restricted at certain sites during particular times of the year because of bird nesting, environmental restrictions or adverse weather conditions. The infrequency of service related visits may have an adverse impact on condition through the prolonged closure of buildings.
- **Complexity of structures** – although the majority of lighthouses and associated buildings are historic structures with listed building status and/or ancient building status, they are functional buildings that have evolved over many years in terms of building components, layout, personnel accommodation and the technology required to support the Aids to Navigation (AtoN). The primary function of these structures is to support the AtoN and therefore, flexibility is required regarding decisions involving such things as paint systems, energy available for ventilation and/or heating and placement of service equipment, electronics and associated fittings.
- **Physical restrictions on conditioning –** In addition to restrictions on building conditioning arising from power availability in off-shore stations, other physical factors can have an adverse impact on building condition management. For example the presence of bulkheads and bunding within a tower may restrict airflow as will an encapsulated fire prevention system that prevents room-to-room ventilation.

These factors make the management of building conditioning a highly complicated and challenging task, which is destined to become increasingly difficult as these historic structures continue to age. However, it is important to note that, in terms of building conditioning, there are positive aspects arising from recent changes to management strategies particularly with regard to the change in use of many buildings associated with mainland stations to holiday lets and visitor centres. This has restored their condition and provided a revenue source for the GLAs, which may become an increasingly important future source of funds.

Together, the three GLAs have responsibility for one of the largest collections of buildings and associated structures with historic and architectural significance in the United Kingdom and Ireland. Ironically, conservation in its strictest sense is not central to the purpose of the three Lighthouse Authorities whose primary aim is:

> *"To deliver a reliable, efficient and cost effective Aids to Navigation service for the benefit and safety of all mariners."* (2020 The Vision)

However, the GLAs have a duty of care for these structures and aim to maintain them to the best possible standards within the context of the aforementioned constraints. This report seeks to provide advice and information regarding 'best practice' in building condition management so that the future of these historic structures and their important role in marine safety is ensured for future generations.

Trinity House:	http://www.trinityhouse.co.uk/index.html
Northern Lighthouse Board:	http://www.nlb.org.uk/
Commissioners of Irish Lights:	http://www.cil.ie/

SECTION ONE: ATMOSPHERIC HUMIDITY AND CONDENSATION: CHARACTERISTICS AND CONTROLS

Environmental conditions at coastal sites reflect the influence of a large body of salt-rich seawater with generally high ambient atmospheric humidity conditions combined with atmospheric moisture that contains a variety of salts. In order to formulate a successful management strategy it is important to have a sound understanding of the factors that regulate these parameters and the nature of their interaction with buildings and the materials that comprise them. It is also important to accept that it is not possible to stop all water ingress into buildings with a resultant emphasis on minimising and managing the natural water/moisture load of the structure.

1.1 BEHAVIOUR OF WATER VAPOUR IN AIR

At a given temperature air is capable of containing a limited amount of water as invisible vapour; the warmer the air the more water vapour it can contain. If moisture laden air comes into contact with a colder surface, either inside the building or an interface within the building fabric, condensation will occur at the temperature at which the air becomes saturated (**Dewpoint**). Water vapour in the air exerts a pressure (**the Vapour Pressure**) and so air containing a large mass of water vapour has a higher vapour pressure than drier air. This pressure will cause vapour to diffuse from high to low pressure areas. The term usually used to describe whether the air is dry or water laden is **Relative Humidity** (**RH**).

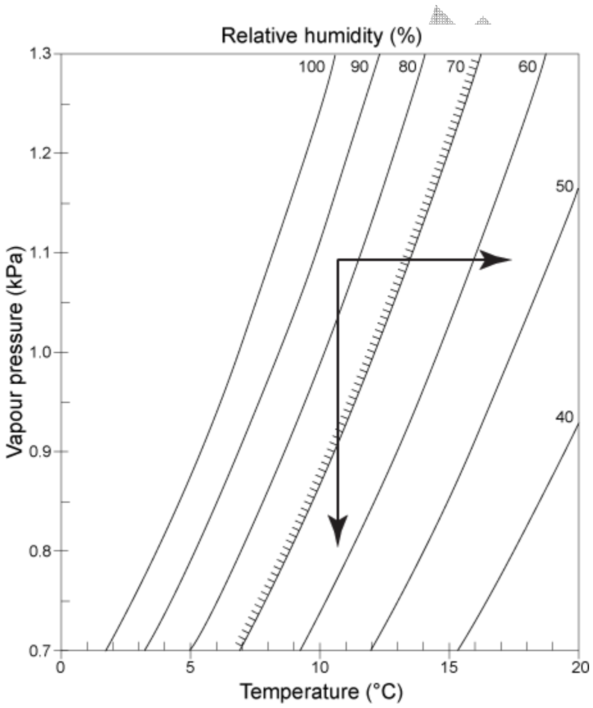


Figure 1: Part of a Psychrometric Chart showing relationship between air temperature, vapour pressure and relative humidity.

The curved lines in Figure 1 show percentage relative humidity (RH) resulting from the combination of temperature and vapour pressure. Percentage relative humidity is a good indicator of the risk of condensation, mould growth and the degradation of absorbent materials. As a general rule, where air remains around or above a 70% RH value for lengthy periods there is a high risk of condensation development and mould growth on some part of the internal fabric.

The arrows shown in Figure 1 indicate that the risk of condensation development can be reduced by increasing the temperature, decreasing the vapour pressure or by a combination of these two factors. A blank Psychrometric Chart is included in Appendix 2. Excess atmospheric moisture and the associated absence or reduction in ventilation within structures, are the main factors that lead to a decline in the internal condition of structures and their fabric and furnishings.

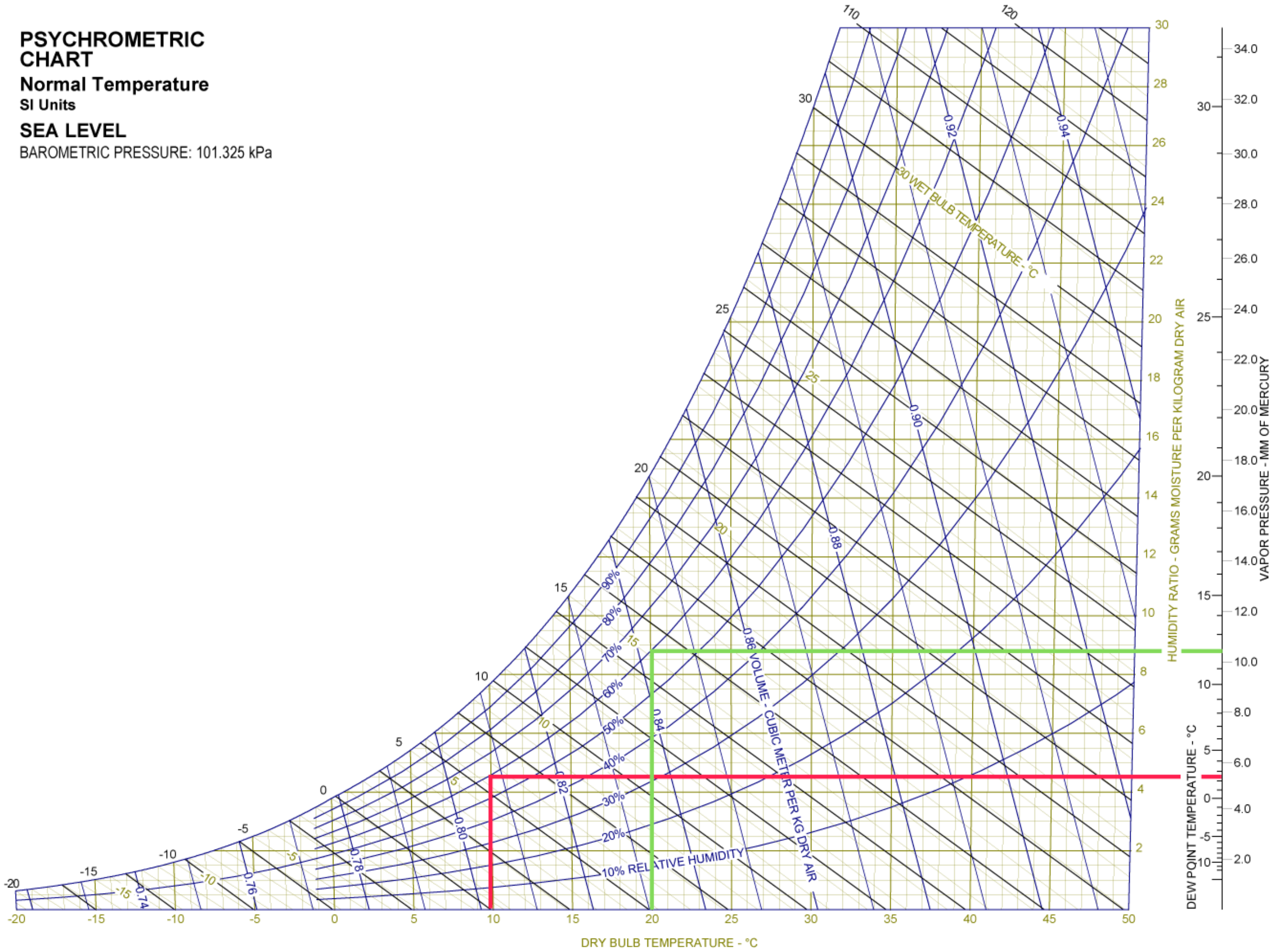


Figure 2: This Psychrometric Chart allows the calculation of dewpoint based on certain known air temperature and relative humidity (RH) parameters. For example, air at 10°C with a RH of 60% has a dewpoint of 2.5°C and moisture content of 4.5g/kg dry air (red line) while air at 20°C with the same RH value of 60% has a dewpoint of 12°C and moisture content of 8.75g/kg dry air (green line)

1.2 CAUSES OF CONDENSATION

There are two types of condensation:

- **Surface or visible condensation –** this type of condensation develops on visible surfaces within the building
- **Interstitial condensation –** this type of condensation develops within or between the layers of the building envelope and can be potentially hazardous because serious damage to building materials such as timber can often go undetected

Most materials will absorb water vapour from the environment and this can take the form of atmospheric humidity, construction water and moisture derived from the presence and action of human occupants (cooking, cleaning, breathing etc.).

1.2.1 Causes of Surface Condensation

Surface condensation will occur on surfaces that are at or below the dewpoint temperature of the air immediately adjacent to them. As shown in Figure 1 the two parameters that control this effect are the **temperature of the surface** and the **vapour pressure of the air**.

The **temperature of a surface** depends upon the following factors:

- **The type(s), amount, time and rate of heating of the building –** Buildings heated on a 24/7 basis rarely show evidence of condensation even in the absence of ventilation. In such cases all surfaces are maintained at the temperature of the heated air with no intervals of cooling that might allow a thermal differential to develop between material surfaces and the air. However, 24/7 heating is expensive, environmentally unsustainable and not possible in many remote locations where there is no mains electricity and power generation is limited and primarily directed towards the Aids to Navigation. Intermittent or partial heating can be problematic with the development of condensation through the creation of a time lag before temperature equalisation occurs between material surfaces and the overlying air due to differences in thermal properties (see below).
- **Cold bridging in the building fabric –** Cold bridges are sections through the building fabric of significantly lower thermal resistance than the rest of the construction. These occur particularly around openings and at the junction of walls and floors and walls and roofs. For example, condensation can occur at the base of externally connecting walls. Concrete and steel framed buildings are particularly prone to cold bridging unless these elements are individually insulated. Cold bridging usually becomes apparent through specific patterns of staining whereby the cold bridge because of the temperature differential attracts moisture as surface condensation, which in turn attracts dirt and dust and can facilitate mould growth. The overall effect of cold bridging is to reduce the effectiveness of any insulation within the building. Cold bridge condensation can also occur on internal structures such as un-insulated cold-water tanks.
- **The thermal properties of the material and its surface finish –** Different materials have different thermal properties that reflect a material’s ability to absorb and conduct heat energy. For example, the thermal or specific heat capacity of a material refers to the quantity of heat energy required to increase

the temperature of a material by a particular amount. Brick, stone and concrete have much higher specific heat capacities than air which means that they take longer to heat than air but they hold onto that heat and will release it relatively slowly back into the building in comparison to air which heats and cools quickly. The significance of differences in thermal properties between materials is the creation of a 'lag effect' when the temperature of walls, floors etc lags behind that of heated air creating conditions conducive to the formation of condensation when warmer air overlies comparatively cooler surfaces.

- **The nature and rate of ventilation –** The absence of, or reduction in, ventilation within a building can raise the potential for the development of condensation because the greater the amount of time a body of moist air is in contact with cooler surfaces such as walls and ceilings the greater the time available for moisture within the air to condense out onto the surface of the material in question. Inadequate ventilation can result in the formation of 'pockets' of static air at wall corners and in rooms where connecting doors have been closed. Prior to automation lighthouse keepers ensured adequate ventilation of towers and associated buildings on a daily basis but this is no longer the case with buildings effectively closed up for long periods between maintenance visits. In such circumstances full use should be made of structural features such as fireplaces and chimney flues, which in the absence of an actively maintained airflow, allow for some limited ventilation.
- **The temperature conditions of the external environment –** In the absence of heating, a building's internal temperature primarily reflects external temperature conditions although it may be somewhat modified by aspect-related heating of rooms by the sun shining through windows. **Reverse condensation** or summer condensation is a product of external temperature conditions and is most frequently observed when the sun shines on damp walls. This is most likely to be encountered in thin masonry walls, walls of an absorbent nature or on walls that remain saturated because of their exposure. It is caused by the moisture within the wall being vapourised by the heating effect of the sun with the resulting pressure difference driving the water vapour towards the inside of the building. The risk of reverse condensation may be reduced by the application of a weatherproofing treatment or system to the outside walls of the building. Reverse or summer condensation can commonly occur on basement floors especially if the basement space is ventilated. Outside air tends to have high moisture content during warm weather and the dewpoint temperature of this air may also be relatively high but as uninsulated basement floors may be colder than the dewpoint of this outside air then condensation will form.

The **vapour pressure of the air** is determined by:

- **The production of water vapour –** the potential for condensation development within a building can be significantly increased by human occupation and associated activities. For example, moisture can be brought in directly on wet clothes and materials, it can released from the burning of gas in cookers and heaters, it can also be released from the act of cooking food, boiling a kettle and through the use of washing machines and unvented driers. Finally, the simple act of breathing can also introduce considerable quantities of water vapour into the internal atmosphere of a building.

- **The nature and rate of ventilation –** Well established airflow decreases the time that moisture-laden air is in contact with cold internal surfaces and thus reduces the potential for condensation development. Passive ventilation through the utilisation of structural features such as the stack effect in tall buildings and the natural draw of air through fireplaces and chimney flues has the advantage of requiring no additional energy input but may lead to the formation of static pockets of air. Active ventilation requires energy input but in comparison to passive systems will be more efficient in terms of air movement and is therefore more likely to be effective in reducing or preventing surface condensation. Possible solutions to this problem include the introduction of solar powered fans and wind catcher units.
- **Moisture content of the replacement 'fresh' air –** Because of their coastal environmental settings, lighthouses and associated buildings are exposed to the effects of naturally moisture-laden and salt-rich air. In addition, the moisture burden can be increased by wave splash and spray and coastal fog. The importation of moisture-rich air could be reduced by use of 'smart' positive ventilation systems whereby ventilation is restricted or deactivated during periods when the external humidity is high (e.g. more than 75%RH) and reactivated when RH values fall.
- **Direct penetration of the building fabric by water –** The central tenet of good building management is to keep the 'weather' out. However, there are many sources from which water can be derived especially in regularly unoccupied buildings where the effects of relatively minor damage or poor/delayed maintenance can accumulate to cause significant damage. Building fabric defects that can lead to the ingress of water include (examples of these defects are shown in Section 4):
    - Badly fitting lantern glazing may facilitate the ingress of rain into the lantern and from there into the body of the tower.
    - Damaged glazing and cracked window putty may facilitate the ingress of driven rain.
    - Degradation of mortar and pointing can create a route for moisture penetration, which once established within masonry, can be extremely difficult if not impossible to eliminate.
    - Penetration of groundwater can occur in buildings that have compartments below ground level with inadequate tanking.
    - Rising damp is a problem associated with many old buildings constructed without a damp-proof course. The extent and severity of the problem will primarily depend on the nature of the building materials and the bedrock and foundation characteristics.
    - Cracks in asphalt (flat roofs) and parapet walls.
    - Damage to roof tiles/slates and lead/copper flashing.
    - Damaged or blocked rainwater goods can lead to prolonged periods of dampness on adjacent walls. In salt-rich marine environments corrosion of lead and copper pipes within masonry walls can result in the significant leakage and spread of water within walls.

  - Close proximity of vegetation and mosses to buildings can lead to moisture retention and can degrade materials/structure by root penetration.

- **The water absorbency of building fabric and contents –** The ability of the building fabric and contents to absorb water vapour (sponge effect) will reduce or increase the vapour pressure within the building depending on whether the building is cooling or warming.

1.2.2 Causes of Interstitial Condensation

The interior of buildings during the winter will usually be warmer and the air will hold more moisture in vapour form than the outside. Because most building materials are permeable to some extent they do not obstruct the movement of moist air through the fabric of the structure. This warm moist air will eventually cool when it comes into contact with concealed surfaces that are below its dewpoint within the fabric of the building resulting in condensation. This form of condensation is called **interstitial condensation** and can result in the potentially serious hidden deterioration of materials and is often associated with spalling/loss of decorative surfaces. The movement of moist air through the fabric of a building can occur by leakage and/or diffusion:

- **Diffusion –** diffusion involves the movement of water vapour through building material from locations of high moisture content towards a location of comparatively lower moisture content (Figure 3). The rate of moisture diffusion will vary depending on the permeability characteristics of the material through which it is moving and the vapour pressure gradient between internal and external conditions. Diffusion can be combated by the use of less porous materials vapour barriers such as films and paint systems.

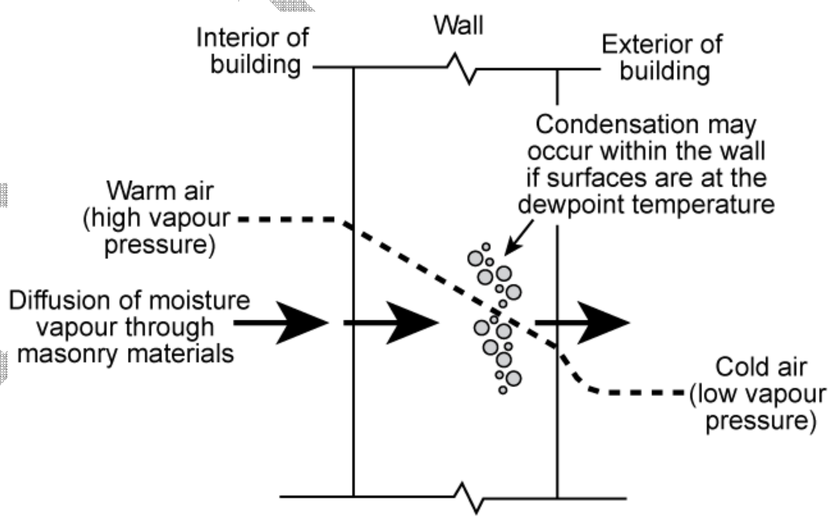


Figure 3: Process of moisture diffusion through a wall

- **Leakage –** leakage of moist air can occur through cracks or fissures in materials. These may be present as material flaws or may have been created, for example, by the drilling of holes in walls and window frames to accommodate electrical cables and drains for dehumidifiers. The rate of leakage will depend on the nature and extent of potential access points for moisture-laden air and also on the vapour pressure differences. Air leakage can only be addressed by judicious maintenance with the sealing of cracks, fissures and openings in interior walls.

In addition to the effects within masonry structures, interstitial condensation has been found to be a major problem within lanterns where double skins are used to form the cast iron murette. Ventilation and, in severe cases, condensate management should be provided to reduce the problem as much as possible by opening up the internal ventilators. Introduction of ventilation within the walls themselves may also help to remove or lessen moisture within masonry and reduce the potential for development of condensation (e.g. the Schrijver System – http://www.schrijversystem.com/english/). If the building control officer gives approval, it is the intention of Trinity House to trial such as system in the tower and cottages at North Foreland (see Figure 5).

1.3 EFFECTS OF HIGH RELATIVE HUMIDITY AND CONDENSATION

In coastal locations high background humidity levels are to be expected and good moisture management strategies are central to the long-term maintenance of building condition. However, in such environments atmospheric humidity is difficult to control and there are many features that are indicative of inadequate management:

- **Condensate –** The effects of condensation can range from the relatively minor comprising the presence of condensate only on kitchen and bathroom windows to the more problematic extensive presence of condensate on walls and floors. The former is more of a nuisance and is of limited significance while the latter may have serious implications for the longevity of furnishings, fabrics and internal surfaces and components.
- **Mould growth –** Mould spores are naturally present and abundant in the atmosphere. Within occupied buildings that are well heated and ventilated they rarely cause a problem. The main factor that is essential for the growth and spread of mould is the persistent presence of moisture on surfaces and within materials. As a general rule if the average relative humidity within a room stays above 70% for prolonged periods of time, sufficient moisture will be available to support the growth and spread of moulds. Once established moulds can actually retain moisture within their structures exacerbating surface wetness. Aside from the implications of mould growth for deterioration of fabrics and fittings it also has serious implications for human health and is therefore a major Health and Safety issue for personnel required to spend time on station.
- **Generalised dampness –** Fabrics and furnishing stored within a damp building will absorb moisture, which will ultimately lead to their gradual degradation. Sustained exposure to damp may contribute to the decay of timber, plasterboard and corrosion of metal fittings.
- **Salt damp –** moisture penetration with salt can result in staining of interior surface finishes as salts reabsorb moisture from the atmosphere when relative humidity rises. This dampness will also tend to attract dust and may facilitate mould growth which will further exacerbate the surface discoloration.
- **Salt accumulation –** The significance of high relative humidity and associated condensation, particularly in a salt-rich environment, is that it provides a mechanism for the wet-deposition, surface accumulation and gradual penetration of salts into the fabric of the building. One of the most commonly occurring salts in these coastal environments is halite (sodium chloride: $NaCl$). Halite is a strongly hygroscopic salt meaning that it attracts moisture from the atmosphere (in a kitchen salt cellars frequently clog up) and is therefore said to be deliquescent. Different hygroscopic salts exhibit particular threshold relative humidity values above which they start to deliquesce. Above the equilibrium relative humidity value (75% for $NaCl$), hygroscopic salts will exhibit deliquescence but if the ambient relative humidity decreases below this value the salt solution will become saturated and with a continued decline in relative humidity salt crystallisation will begin. With the accumulation of salt, regular episodes of salt crystallisation followed by periods of deliquescence allow salts in solution to penetrate and exploit naturally occurring weaknesses within masonry material (for further information see Appendix 3). The accumulation of salts resulting from condensation will also have adverse implications for any

exposed metal fittings and electronics that are prone to corrosion. Salt accumulation can also occur as a result of the interaction between fumes from inadequately vented internal fuel storage tanks and salt rich moisture within masonry materials. The volatile hydrocarbons from the fumes combine with sodium salts to form a suite of particularly aggressive sulphate salts.

The persistence of excess moisture within a building will quickly make its presence known through many of the above features. Prompt intervention can prevent a relatively minor problem developing into a major issue with widespread adverse implications throughout a structure. Table 1 gives some more specific examples of the hazardous effects of condensation within lighthouses and associated buildings.

Table 1: Common effect of condensation on interior fittings and fixtures of lighthouses and associated buildings

Hazard	Effect
Mould growth	**Health impacts**: the presence of mould spores can have serious effects on human health when inhaled, especially for personnel with chronic health disorders such as asthma and bronchitis. (N.B. Health and Safety Legislation requires that the working and accommodation environments should not be hazardous to the health of personnel) **Soft furnishings**: mould growth within damp furnishings can lead to the staining, breakdown or rotting of fabrics. Mould can also cause foxing of paper **Timber**: penetration of timber joints by moisture facilitates the ingress of spores and development of mould that can lead to the breakdown and rotting of the timber **Painted surfaces**: extensive and well-established mould growth results in unsightly discoloration of painted surfaces
Corrosion	**Metal fittings** (e.g. handrails, screws and nails etc): condensation and associated salt accumulation can lead to rapid corrosion **Electrical items**: condensation and high humidity can lead to corrosion of electrical contacts, printed circuit boards and where surfaces are damp, increases the risk to personnel of electric shock
Damage to surface finishes	**Wallpaper**: Under conditions of condensation wallpaper will become stained and will start to peel away from the wall **Soft distempers**: these are liable to breakdown through flaking when exposed to repeated wetting and drying **Paint**: when moisture penetrates behind painted surfaces this will often result in the creation of blisters with the eventual fragmented loss of the painted surface **Plaster**: under extreme conditions plaster may become unstable and break away from the underlying surface **Lath and plaster detachment**: corrosion of nails fixing lath and plaster to wall-mounted wooden batons can result in its destabilisation and eventual detachment
Fogging	Condensation can form on lantern glazing resulting in a fogging of the light. In exceptional conditions condensation can also affect lenses with significant implications for light generation

2. SECTION TWO: BUILDING CONDITIONING

2.1 FACTORS INFLUENCING BUILDING CONDITION

Successful condition management of structures exposed to marine environments is extremely challenging and reliant on an understanding of the complex interactions between factors such as:

- **The design of the building(s) –** Building design can have a significant influence on factors such as ventilation, heating and moisture movement. For example, a tall tower will benefit from natural ventilation developed through the 'stack' effect with warm air rising and drawing in replacement air. The efficiency of this natural form of ventilation will depend on the internal structure of the tower with features such as floors, staircases and closed doors inhibiting airflow. The presence of structural features such as fireplaces and chimney flues will also facilitate ventilation within a building provided they are not closed up (Figure 4). Another significant factor is the presence or absence of a damp-proof course.

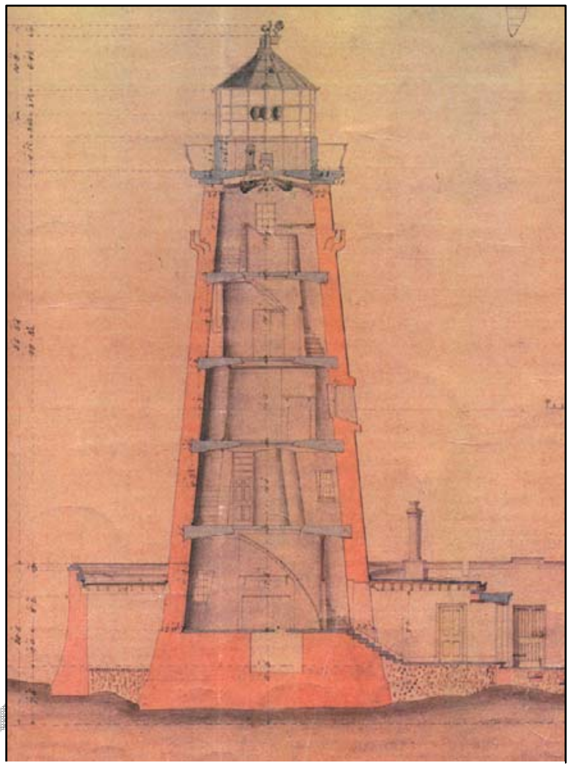


Figure 4: Section drawing of Longstone lighthouse showing chimney flues and outlets within the external walls on the 4th and 5th floors (TH site 3 in Figure 7)

- **The history of the building(s) –** In historic structures, present-day management is often heavily influenced by a legacy of past events. For example, major storm damage in the past, which may have resulted in the ingress of seawater, can leave masonry materials contaminated with salt and moisture and initiate the cycle of salt weathering and corrosion-related damage. In addition, as many of these structures are more than 100 years old, the gradual aging and degradation of the masonry components of the building can reduce their efficiency in preventing moisture penetration.

- **Materials used in construction –** Materials used in building construction can greatly influence long-term building condition. For example, different materials have different permeability and thermal characteristics, which can lead to the creation of cold-bridging and increase the potential for condensation when buildings are unheated. In addition certain building materials are more prone to the long-term effects of salt and moisture than others. Because of their age, many lighthouses have undergone significant structural modification that has introduced different building materials and methods. Consequently, knowledge of the construction history of the structure is extremely important in condition management with referral to archive drawings and plans e.g. North Foreland (Figures 5a–c) (TH site 13 in Figure 7). In addition, poor specification of material used in repairs and/or replacement can be the source of significant problems with the most common example being the replacement or repair of lime mortar with 'hard' cement, which lacks the flexibility and breathability of the original lime mortar.

Figure 5: Historic plans and drawings of North Foreland lighthouse provide a valuable record of significant structural changes that have had a major impact on present-day building conditioning. (a) The original flint and brick finish of the tower, (b) subsequent rendering of the exterior of the tower and, (c) construction of a rounded internal structure within the original octagonal tower which has given rise to considerable stresses between different masonry materials and problems related to moisture movement and reduced breathability.

- **Exposure characteristics of the building's location –** Lighthouses and their associated structures are by their very nature exposed to extreme environmental conditions. However, the extremity of these conditions varies from site to site and, in general, those located on the western, north-western and south-western coasts are exposed to the harshest conditions in terms of driven rain and high wind-speeds. In addition to the effects of wind-driven rain, many lighthouses such as Orfordness (TH site 12 in Figure 8) are increasingly at risk from the effects of coastal erosion, sea-level rise and the increased severity of storm events associated with climate change (Figure 6). In the next 50 years this will become an increasingly significant issue with regard to building conditioning because of the associated impact of rising groundwater and storm surges.

Figure 6: Orfordness Lighthouse located on a shingle spit which is undergoing significant coastal erosion that will eventually jeopardise the structural stability of the tower

- **Available energy for conditioning –** Building location also has an impact on the energy available for conditioning with those stations located off-shore and away from mains electricity being dependent on energy generated by other sources. This may result in an unavoidable energy shortfall for building conditioning as the primary call on available energy is for the operation of the Aids to Navigation.

It is important to remember that in situations where internal building condition has been deteriorating for sometime through the accumulation of salts, salt damage and moisture in materials there will be no 'quick-fix' when attempting to improve condition. Improvement in condition under such circumstances may take time involving a period of gradual improvement as the building adjusts to moisture control measures.

2.2 DEFINING ACCEPTABLE BUILDING CONDITION

Lighthouses and their associated structures when built where designed for permanent occupation with the maintenance of good building condition being reliant on regular heating and ventilation. However, in the post-automation period with remotely operated Aids to Navigation it has to be accepted that in the absence of keepers these buildings cannot be maintained at the same high level of condition. There is no single definition of what constitutes acceptable ‘building condition’ as this will vary depending on the functional requirements of each structure. For example, the condition of a structure that is operational but never occupied may not be required to be maintained to as high a standard as one that is regularly occupied by maintenance personnel or open to the general public.

This type of approach to determining the ‘acceptable’ level of building conditioning is essential given budgetary restrictions that require a balance to be struck between limiting the number of expensive maintenance visits without jeopardizing the long-term integrity of the structure. Consequently, successful building conditioning represents a compromise between ‘acceptable’ and ‘ideal’ levels of deterioration of the building fabric and supportive intervention.

Assigning lighthouses and their associated structures to an operational category is the first step in identifying the relevant ‘acceptable’ standard of building condition to be maintained. The categories to which buildings can be assigned are shown below with details of the ‘acceptable’ standard of building condition for each category given in Table 2. The description of condition characteristics for each of these categories is adapted from the Trinity House Star Rating System:

- **Category 1**: Operational and frequently occupied (overnight etc.)
- **Category 2**: Operational and infrequently occupied (day visits, emergency shelter etc.)
- **Category 3**: Operational but unoccupied
- **Category 4**: Non-operational

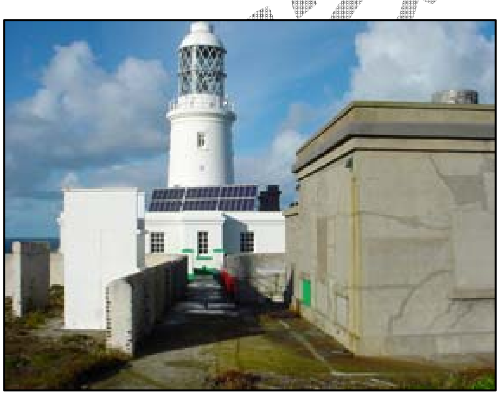


Figure 7: An example of different categories of condition with the operational lighthouse painted while the non-operational redundant engine room in the foreground is left unpainted (Round Island – TH site 31 in Figure 8).

It is important to note that within a complex of buildings some may be assigned to different categories, for example, the tower may be a Category 1 structure while keepers’ cottages may be Category 2 with unused outbuildings identified as Category 4 (Figure 7).

It is also important to note that these condition categories are essentially aspirational as in reality a building assigned to Category 1 may not attain all the desired set of condition characteristics outlined in Tables 2a and 2b. The important fact is that these characteristics are goals to be aimed for when formulating building conditioning strategies.

Table 2a: Building condition indicators for operational categories of towers, cottages and outbuildings

CONDITION CATEGORY	TOWERS *	ACCOMMODATION	OUTBUILDINGS
CATEGORY 1: Operational & frequently occupied (overnight etc.)	**Structure**: Structurally sound with only minor defects & superficial surface cracking evident. Gallery structurally sound with roof & roof access in good decorative order, weather-tight & structurally sound. **Paint & Finishes**: Tower painted as Schedule 1 day-mark with no significant deterioration of paintwork. All paint finishes in generally good condition with no evident rust streaking or blemishes. **Joinery**: In good condition with specified paint or varnish coverage as appropriate. **Windows & Doors**: Glazing in good condition with no leaks or cracked panes. Windows & external doors weather-tight & in sound condition. **Internal environment**: Generally free from condensation & damp with heating, ventilation & facility systems fully operational.	**Structure**: Structurally sound with only minor surface defects & superficial cracking evident. Roof & rainwater goods in very good condition, weather-tight & structurally sound. **Paint & Finishes**: External masonry painted as Schedule 1 day-mark with no rust streaking or staining evident. No significant deterioration or blemishes evident on interior & exterior paintwork. **Joinery**: In good condition with specified paint or varnish coverage as appropriate. **Windows & Doors**: Glazing in good condition with no leaks or cracked panes. Windows & external doors weather-tight & in sound condition. **Internal environment**: No evidence of damp & condensation with heating & facility systems fully operational.	**Structure**: Structurally sound with only minor surface defects & superficial cracking evident. Roof & rainwater goods in very good condition, weather-tight & structurally sound. **Paint & Finishes**: External masonry painted as Schedule 1 day-mark with no rust streaking or staining evident. No significant deterioration or blemishes evident on interior & exterior paintwork. **Joinery**: In good condition with specified paint or varnish coverage as appropriate. **Windows & Doors**: Windows & external doors weather-tight & in sound condition. **Internal environment**: Generally free of damp & condensation. If installed, heating & facility systems fully operational.
CATEGORY 2: Operational & infrequently occupied (day visits, emergency shelter etc.)	**Structure**: Structurally sound but shows minor cracking which is monitored. Gallery structurally sound with roof & roof access in good decorative order, weather-tight & structurally sound. **Paint & Finishes**: Tower painted as Schedule 1 day-mark with some deterioration of paintwork. Paint finishes show some evidence of rust streaking &/or blemishes. **Joinery**: In generally good condition with specified paint or varnish coverage as appropriate. Minor deterioration may be evident. **Windows & Doors**: Glazing in good condition with no leaks or cracked panes. Windows & external doors weather-tight & in sound condition. **Internal environment**: Minor evidence of condensation but not sufficient to cause fabric damage or damage to Aids to Navigation systems. Heating, ventilation & facility systems fully operational.	**Structure**: Structurally sound with minor surface defects & cracking evident on internal &/or external surfaces which is monitored. Roof & rainwater goods in good condition, weather-tight & structurally sound. **Paint & Finishes**: External masonry painted as Schedule 1 day-mark with some rust streaking, staining & blemishes evident. Internal paintwork generally sound with some blemishes. **Joinery**: In good condition with specified paint or varnish coverage as appropriate. Some minor deterioration of paint/varnish film evident. **Windows & Doors**: Glazing in good condition with no leaks or cracked panes. Windows & external doors weather-tight & in sound condition. **Internal environment**: Minor evidence of damp & condensation but insufficient to cause fabric damage. Heating & facility systems fully operational.	**Structure**: Structurally sound with minor surface defects & cracking evident on internal &/or external surfaces which is monitored. Roof & rainwater goods in good condition, weather-tight & structurally sound. **Paint & Finishes**: External masonry painted as Schedule 1 day-mark with some rust streaking, staining & blemishes evident. Internal paintwork generally sound with some blemishes. **Joinery**: In good condition with specified paint or varnish coverage as appropriate. Some minor deterioration of paint/varnish film evident. **Windows & Doors**: Windows & external doors weather-tight & in sound condition. **Internal environment**: Minor evidence of damp & condensation but insufficient to cause fabric damage. If installed, heating & facility systems fully operational.

Condition indicators for each category have been adapted from the Trinity House Star Rating System
**N.B. Rock Towers may be unpainted both internally and externally and still be classified as Category 1 stations*

Continued overleaf/

Table 2a continued

CONDITION CATEGORY	TOWERS	ACCOMMODATION	OUTBUILDINGS
CATEGORY 3: Operational but unoccupied	**Structure**: Structurally sound but shows minor cracking which is monitored. Gallery structurally sound with roof & roof access in good decorative order, weather-tight & structurally sound. **Paint & Finishes:** Tower unpainted. Paint finishes show evidence of rust streaking &/or blemishes with flaking or peeling of internal masonry paintwork. **Joinery**: In generally good condition with specified paint or varnish coverage as appropriate. Some deterioration of paint film is evident. **Windows & Doors**: Glazing in good condition with no leaks or cracked panes. Windows & external doors weather-tight & in sound condition. **Internal environment**: Some dampness or condensation is evident but not sufficient to cause fabric damage or damage to Aids to Navigation systems – regular monitoring is required. Heating systems & other installed facilities function adequately without faults.	**Structure**: Structurally sound with surface defects & cracking evident & monitored. Roof & rainwater goods in fair condition, weather-tight & structurally sound. **Paint & Finishes:** External masonry either unpainted or reverting to natural state with some rust streaking & staining evident. Internal paintwork flaking & peeling. **Joinery**: In sound condition with specified paint or varnish coverage as appropriate. Some deterioration of paint/varnish film evident. **Windows & Doors**: Windows & external doors weather-tight & in sound condition but may be boarded up. **Internal environment**: Damp & condensation is evident but being monitored. Any facilities or heating systems installed are in an operational condition.	**Structure**: Structurally sound with surface defects & cracking evident & monitored. Roof & rainwater goods in fair condition, weather-tight & structurally sound. **Paint & Finishes:** External masonry either unpainted or reverting to natural state with some rust streaking & staining evident. Internal paintwork flaking & peeling. **Joinery**: In sound condition with specified paint or varnish coverage as appropriate. Some deterioration of paint/varnish film evident. **Windows & Doors**: Windows & external doors weather-tight & in sound condition but may be boarded up. **Internal environment**: Damp & condensation is evident but not causing fabric damage and is being monitored. Any facilities or heating systems installed are in an operational condition.
CATEGORY 4: Non-operational	**Structure**: Structurally sound with superficial defects & surface cracking evident. Gallery structurally sound with roof & roof access weather-tight & structurally sound. **Paint & Finishes:** Tower unpainted. Internal paint finishes will be flaking & peeling with evidence of rust streaking &/or blemishes on exterior surfaces. **Joinery**: Deterioration of specified paint or varnish evident & will require regular monitoring to prevent rot. **Windows & Doors**: Glazing in good condition with no leaks or cracked panes. Windows & external doors weather-tight & in sound condition. **Internal environment**: Damp & condensation is evident. No heating or facilities provided.	**Structure**: Structurally sound with defects & cracking evident & monitored. Roof & rainwater goods in fair condition, weather-tight & structurally sound. **Paint & Finishes:** External masonry unpainted with rust streaking & staining evident. Extensive flaking & painting of internal paintwork. **Joinery**: In generally sound condition but with evidence of paint &/or varnish deterioration. **Windows & Doors**: Windows & external doors may be boarded up. **Internal environment**: Damp & condensation is evident but being monitored. No heating or facilities provided.	**Structure**: Structurally sound with defects & cracking evident & monitored. Roof & rainwater goods in fair condition, weather-tight & structurally sound. **Paint & Finishes:** External masonry unpainted with rust streaking & staining evident. Extensive flaking & painting of internal paintwork. **Joinery**: In generally sound condition but with evidence of paint &/or varnish deterioration. **Windows & Doors**: Windows & external doors may be boarded up. **Internal environment**: Damp & condensation is evident but being monitored. No heating or facilities provided.

Condition indicators for each category have been adapted from the Trinity House Star Rating System
**N.B. Rock Towers may be unpainted both internally and externally and still be classified as Category 1 stations*

Table 2b: Building condition indicators for operational categories of boundary walls, grounds, boat landings and sea defences

CONDITION CATEGORY	BOUNDARY WALLS, FENCES & GATES	ROADS, GROUNDS & COURTYARDS	BOAT LANDINGS & SEA DEFENCES
CATEGORY 1:	**Walls**: Structurally sound with mortar joints in good condition. Walls painted & in good condition with some minor blemishes. **Fences:** Rails & posts in good condition with no damage evident. **Gates**: Gates & hinges in good working order with no rot or rust evident. **Woodwork**: All woodwork to be protected by paint, varnish or other wood treatment & in good overall condition.	**Vegetation**: Grassed areas and hedges kept in tidy condition. **Asphalt & Concrete:** In sound condition & free from potholes & weeds. **Access steps & ramps**: In sound & safe condition.	**Walls**: Structurally sound with mortar joints in good condition. **Handrails:** Where fitted should be structurally sound & in good decorative order. **Slipways:** Slipways, landings & steps to be structurally sound & clear of weed. **Ladders & Safety equipment**: Where fitted should be structurally sound & free from defects. **Woodwork & Fittings**: All woodwork, composite fenders & ancillary fittings in good order & defect free.
CATEGORY 2:	**Walls**: Structurally sound with mortar joints in good condition. Walls unpainted or reverting to natural state. **Fences:** Rails & posts in good condition with no damage evident. **Gates**: Gates & hinges in good working order with no rot or rust evident. **Woodwork**: All woodwork to be protected by paint, varnish or other wood treatment.	**Vegetation**: Grassed areas and hedges kept in manageable condition. **Asphalt & Concrete:** In sound condition but may have some minor potholes & weeds. **Access steps & ramps**: In sound & safe condition.	**Walls**: Structurally sound with mortar joints in good condition. **Handrails:** Where fitted should be structurally sound. **Slipways:** Slipways, landings & steps to be structurally sound & clear of weed. **Ladders & Safety equipment**: Where fitted should be structurally sound & free from defects. **Woodwork & Fittings**: All woodwork, composite fenders & ancillary fittings, if fitted, in good order & defect free.
CATEGORY 3:	**Walls**: Walls maintained in safe condition & unpainted. **Fences:** Maintained in safe condition unless removed. **Gates**: All gates removed. **Woodwork**: All woodwork removed.	**Vegetation**: Grassed areas and hedges are in an unmanaged condition. **Asphalt & Concrete:** In sound condition but may have some minor potholes & weeds. **Access steps & ramps**: In sound & safe condition.	**Walls**: Structurally sound with mortar joints in good condition. **Slipways & Landings:** Where these are formed from, or cut into the natural rock, surfaces should be sound and free of weed. **Handrails:** If fitted, should be structurally sound. **Safety equipment**: If fitted, should be complete & defect free. **Woodwork & Fittings**: Any woodwork, composite fenders & ancillary fittings, if fitted, should be in good order & defect free.
CATEGORY 4: Non-operational	**Walls**: Walls left to weather to natural state. **Fences:** All fences removed. **Gates**: All gates removed. **Woodwork**: All woodwork removed.	**Vegetation**: Grassed areas and hedges are completely wild. **Asphalt & Concrete:** In poor condition with potholes & weeds. Evidence of widespread surface disintegration. **Access steps & ramps**: In sound & safe condition.	Landings abandoned

Condition indicators for each category have been adapted from the Trinity House Star Rating System

2.3 METHODS OF BUILDING CONDITION

In terms of building conditioning, it is important to recognise that there is no single prescribed approach. Each station will require individual assessment and the development of a strategy appropriate for that particular station's needs reflecting factors such as the station layout, energy availability, the current condition of the station, its operational category and any associated operational restrictions. Increasingly, greater reliance is being placed on the use of energy from renewable energy sources to cover building conditioning requirements, especially on off-shore stations where mains electricity is not available.

When compiling a building conditioning strategy several factors have to be considered:

- Station Asset Plan & identification of operational category (1–4)
- Provision of ventilation
- Provision of heating
- Dehumidification
- Use of specialist building systems and finishes

2.3.1 Station Asset Plan and Identification of Operational Category

The first step in the compilation of a strategy for building conditioning is the development of a Station Asset Plan. This document forms the basis of a 10 year work plan for the station and should identify the long-term operational category of the station in question (categories 1–4) which is central to defining short (2 year) to medium-term (5 year) condition management goals and work programmes for each building within the station complex.

2.3.2 Provision of Ventilation

In this post-automation era, one of the most challenging issues with regard to building conditioning is ventilation or more accurately, insufficient ventilation. The primary effect of ventilation is to control humidity levels and reduce the potential for condensation development by keeping moist air moving over cold internal surfaces thereby preventing it from cooling and condensing. Ventilation can be either;

- **Natural** – structural characteristics of buildings can facilitate natural airflow. The prime example of this is the through flow of air generated by the stack effect in a tall building where warm air rises from the base, is expelled from the top of the tower and replaced by air drawn in from outside. Natural ventilation may be insufficient in certain buildings to maintain adequate airflow and it is important to note that this form of ventilation will only occur if vents exist for the drawing in and expellation of air. If ventilation in a building is reliant on natural processes then it is important that connecting doors within the building are left open unless the risk of fire is considered to be high
- **Forced** – forced or fan assisted ventilation requires power and maintenance but produces a regulated airflow that can be controlled by humidistats. Forced ventilation systems may be necessary to supplement natural airflow and thus

avoid the development of static pockets of stale, damp air that lead to localised condensation.

- **Positive pressure –** natural through flow ventilation may not always be practical for lighthouses and associated buildings. An alternative method of ventilation, which has found favour with many Local Authorities and Housing Associations is Positive Pressure Ventilation using systems such as the Daisy Combi Positive Pressure Ventilation Unit. This is an extension of the intake ventilation concept. This rate of ventilation is very low, half an air change per hour, and is designed to be continuous. The concept underlying this method is that outside air is usually drier than inside air, BS5925 (1991 Section 4.5; Control of Internal Humidity) states that "The contribution made by ventilation is to lower the moisture content of the internal air by dilution with the outside air which has a lower moisture content." Whether this last statement reflects what happens in lighthouses is debatable. Positive Pressure Ventilation introduces dryer air into the dwelling where it is mixed with the internal air lowering the total moisture content and gently removing the moist air by forced natural leakage around doors, windows and chimneys. If the building is sealed and draught proofed it may be possible to fit devices to allow the air to escape or devices that open and close automatically depending on temperature, moisture content or both. The air at ceiling level is usually up to 8°C warmer than at lower levels as heated air naturally rises. This stratification was evident in rooms where heavy smoking occurred where heated air rose to ceiling level creating a barrier for the cigarette smoke, which visibly hung some distance below ceiling level. In a domestic environment positive pressure ventilation mixes this wasted heat at higher level, with the dryer outside air and circulates it, firstly across the room at ceiling level, then to the rest of the room volume without any noticeable draughts. As dry air costs less to heat than moist air, and the room air is de-stratified, this form of ventilation should reduce heating bills, despite bringing in a small amount of outside air, which may be below the internal air temperature at certain times of the year.
- **Ventilation heat exchangers –** In cold weather, the provision of heating and the provision of ventilation give rise to a conflict of interests. In order to maintain a certain temperature or temperature difference, increased ventilation (either natural or forced) increases demands on energy input. In heating terms, an airflow rate of 60 l/s costs 72W/ºC sustained temperature difference. This flow rate is about half an air change per hour for a medium sized tower (20m high x Ø5m). One solution to this problem is ventilation with heat recovery, whereby supply and extract ventilation are provided by a device that incorporates a heat exchanger. The extracted air gives up heat to the supply air at an effectiveness that can be as high as 80%. There is a small energy penalty for this heat recovery that is equivalent to the airflow resistance through the heat exchanger. Using heat recovery ventilation, about 50W/ºC could be recovered for a fan energy input of about 40W, irrespective of temperature difference. A temperature difference of 5ºC above ambient would be sufficient to combat condensation problems. Using the same sized tower as an example, energy input without heat recovery would be 360W, 150W with 70% heat recovery.

2.3.3 Provision of Heating

To minimise surface condensation, the timing and amount of heating should be regulated to ensure that surface temperatures inside the building are kept above the dewpoint temperature. Ideally, the aim should be to maintain an air temperature difference of 5°C above ambient in all parts of the building. There are many different types of heaters and their choice will primarily depend on energy available and the area to be heated. It is important to remember that the requirement for heating will be dictated by the operational status of the building with, for example, Category 4 buildings left unheated.

2.3.4 Dehumidification

The aim of dehumidification is to reduce and control the moisture content of air, ideally between 40-70%. There are many types of systems available to reduce atmospheric moisture but all require power and regular maintenance and need to be sited judiciously in order to avoid localised deterioration of joinery, masonry materials and associated surface paint finishes as dehumidification forces the crystallisation of surface salts.

With the exception of accommodation, establishing adequate ventilation is more important in terms of overall building conditioning than dehumidification. However, in buildings where personnel accommodation necessitates the storage of furniture and soft furnishings such as bedding, curtains etc, dehumidification in a confined space such as a bedroom in association with good ventilation will be important for preventing damp and mould growth.

2.3.5 Use of Specialist Building Systems and Finishes

Certain measures can be taken to design against condensation problems. The two aspects of the building to be considered in terms of paint are external and internal surfaces.

External surfaces - historically, many buildings have been externally rendered using cement, which although hardwearing and protective, does not allow masonry materials to breathe. This, combined with the widespread use of impervious, non-breathable paint systems has created a situation whereby the lack of external breathability prevents moisture escaping from the interior of the structures. Replacing a paint system may not be cost-effective but may sometimes needs to be considered in situations where there are significant problems of excessive moisture content in the interior environment and within masonry materials. With regard to external paint systems there are three options:

- **Option 1 –** continue using the traditional alkyd, acyrlated, epoxy, masonry (e.g. ‘Weathershield’) or polyurethane paint systems. The main disadvantage associated with these is that they do not allow masonry surfaces to breathe and do not bridge structural movement cracks.
- **Option 2 –** repair defective coatings and overpaint with elastomeric systems for crack bridging. These paints have a certain level of breathability but this decreases over time when additional coats of paint are applied.
- **Option 3 –** remove existing coating and replace with a breathable system such as Kiem system (mineral) or with ‘Option 2’ to give flexibility as well as breathability to facilitate water vapour release.

It is important to remember that where primary colours are required for day-mark identification, breathable paint systems are less flexible with regard to colour choice.

Internal surfaces – where buildings are unoccupied, particularly towers, it is preferable to remove paint so that masonry surfaces can breathe, although paint systems such as 'Kiem' can be applied after, which allows the passage of water vapour. Paint films can be allowed to degrade naturally and peel or flake off but this can often look unsightly and can be a health issue as most of the old coatings could contain lead. Moisture removal from masonry materials can be assisted by good ventilation and the use of specialist masonry humidity regulating systems such as natural damp courses (e.g. Schrijver System – http://www.schrijversystem.com/english/). However, it is important to note that where relevant, listed building approval may be required before such systems can be fitted.

In some situations condensation has to be accepted as inevitable for example around windows, but its impact can be lessened by using historic drainage channels to trap and carry any moisture away from masonry surfaces (normally found blocked with paint) or by improving insulation by dry-lining with for example, dense insulation/plaster-board materials.

2.4 POWER GENERATION AND BUILDING CONDITIONING SYSTEMS

There are many different approaches to building conditioning but the approach adopted at any given site will depend on energy availability and the operational status of the station with frequently visiting personnel requiring a higher grade of building conditioning. The most important factor is the availability of energy and increasingly the emphasis has shifted from dependence on fossil fuel generation systems to a greater reliance on energy from renewable sources. Following is an overview evaluation of different energy sources and associated building conditioning systems with consideration of issues such as installation and running costs etc. These should be viewed in the context of the comparative analysis of energy generation systems shown in Table 11.

2.4.1 Mains Power Systems

Mains power is typically used for conditioning land-based stations with a direct connection to the national grid. With regard to off-shore stations, mains power is only an option when a short distance has to be covered by cable (e.g. Needles Lighthouse, Isle of Wight – TH site 19 in Figure 8)).

Table 3: Evaluation of mains electricity power provision

System Evaluation Criteria	System Characteristics
Power availability	Constant
Environmental impact locally	Low
Environmental impact at source	Medium
Heating, dehumidification, ventilation	Available
Planning, environmental and listed building consent implications	Limited problems
Initial cost of project and building preparation	Medium
Projected costs of servicing installation (annually)	Low
Life expectancy of system parts	Full life guarantee

2.4.2 Gas Heating Systems

The use of portable propane gas cylinders is used to provide heating via a wet radiator system. The main problems associated with this approach are transport of gas bottles and boiler maintenance.

Table 4: Evaluation of gas heating systems

System Evaluation Criteria	System Characteristics
Power availability required	Adequate gas supply & power for boiler & pump
Environmental considerations	Low
Heating	Depends on boiler efficiency
Planning, environmental and listed building consent implications	Maybe required for boiler house and cylinder housing
Initial cost of project and building preparation	Medium
Cost of fuel & transport (air &/or boat)	Medium
Projected costs of servicing installation (annually)	Low
Life expectancy of major parts and/or installation	No guaranteed life

2.4.3 Cyclic Power Generation Systems

Cyclic power generation systems are generally used where mains power is not available and the load requirements are high. The concept underpinning cyclic power systems is to match battery characteristics to load demands whereby a continuous discharge appears on the battery until a pre-defined level is reached when the batteries undergo rapid recharging. Batteries must start from 100% capacity at the beginning of each cycle with this capacity being slowly reduced in response to load demands. When logged battery capacity drops to 40% an alternator is activated and recharging begins. Cyclic power generation systems are remotely monitored with an over-ride option available that allows initiation of additional battery charging if required.

Table 5: Evaluation of cyclic power generation systems

System Evaluation Criteria	System Characteristics
Power availability	DC / Periodic AC
Environmental considerations	High
Waste exhausts and oil	Moderate waste implications
Heating, dehumidification, ventilation	Short-term availability
Planning, environmental and listed building consent implications	Maybe required for system installation
Initial cost of project and building preparation	High
Cost of service vessels and helicopter time	Medium / High
Cost of fuel	Medium
Cost of storage and bunding to prevent leakage	Low / Medium
Projected costs of servicing installation (annually)	Medium
Life expectancy of major parts and/or installation	Expected 15 years – no guarantee

2.4.4 Oil-based Power Generation

Due to the complexity of most energy generation systems, oil-based power generation for heating is still widely used because of its relatively simple requirements that include a wet heating radiator system and a boiler. The main problems associated with this form of power generation for conditioning is the cost of oil, transport costs and environmental impact. A boiler specifically designed for maritime use is the KABOLA system which can operate from a 24 volt power supply without pre-heating. Renewable energy sources can comfortably provide this energy requirement.

Table 6: Evaluation of oil-based KABOLA boiler power generation system

System Evaluation Criteria	System Characteristics
Power availability required (renewable energy sources)	Initially high installation costs with pay-back due to minimal running costs
Fuel use	Low
Environmental considerations	Low
Heating	Tested system
Listed building consent implications	Not required
Initial cost of project and building preparation	Medium
Cost of fuel & transport (air &/or boat)	Medium (few trips required)
Projected costs of servicing installation (annually)	Low
Life expectancy of major parts and/or installation	No guaranteed life

2.4.5 Solar Power Generation Systems

Although the set-up costs for small-scale solar energy generation are high, solar energy can be used to heat water/glycol heat collection panels for use in a central heating system and to generate electricity via photovoltaic units. Output is greatly dependent on climatic conditions especially in the UK and Ireland where there are significant differences between summer and winter output and also significant latitudinal differences in receipt of solar energy. During long periods of low sunlight levels additional power sources will be required to supplement the systems.

Table 7: Evaluation of solar power generation systems

System Evaluation Criteria	System Characteristics
Power availability required (renewable energy sources)	Medium
Supplementary power	Advisable for poor weather conditions
Environmental considerations	Low waste but High visual impact
Heating	Low–Medium
Structural implications	Possible roof loading issues
Listed building consent implications	Will be required
Initial cost of project and building preparation	Medium–High
Projected costs of servicing installation (annually)	Low
Life expectancy of major parts and/or installation	10 years

2.4.6 Wind Turbine Power Generation

Wind turbines can have either a horizontal or vertical axis and are available in a variety of generation capacities. Small (e.g. Airmarine 403 Units) to medium capacity (e.g. Proven WT2500) wind turbines are ideal for lighthouse installations although the smaller units tend to have a more limited life span because of their high rotation speeds and resultant stress on components. When combined with solar energy generation systems, small-scale wind turbine energy production can provide sufficient power for year round building conditioning. The only possible negative aspects associated with wind turbines are noise, turbine reliability and the visual intrusion of turbines in the context of listed building status.

Table 8: Evaluation of wind turbine power generation systems

System Evaluation Criteria	System Characteristics
Power availability from small to medium-sized units	Estimated at <1–6kW
Supplementary power (e.g. solar)	Advisable for calm weather conditions
Environmental considerations (noise, visual impact)	Medium visual impact, possible implications for nesting birds
Heating, dehumidification & ventilation	Lack of constant power stream may be a problem
Listed building consent implications	Will be required
Initial cost of project and building preparation	Medium
Projected costs of servicing installation (annually)	Low
Life expectancy of major parts and/or installation	Dependent on weather conditions but estimated at 6 years for small units

2.4.7 Tide and Wave Power Generation

Although tidal and wave energy generation systems have been widely trialled, no small-scale system has, as yet, been sufficiently robust due to the rigorous conditions of exposure in the marine environment. The only systems that might be appropriate if they could be reduced in size are the Pile Generator and Gull Wave/Limpet systems. Although these would be comparatively more expensive than other forms of renewable energy systems the power source is dependable on a year-round basis.

Table 9: Evaluation of tide and wave power generation systems

System Evaluation Criteria	System Characteristics
Navigation (Pile or floating systems)	Major shipping hazard
Cost of civil works or anchoring installation	Very High
On-shore civil works	Major disturbance
Environmental considerations	May be unsightly
Maintenance access	Weather dependent
Distance of installation from buildings	Cable length & voltage loss
Listed building consent implications	May be required
Initial cost of project and building preparation	Very High
Projected costs of servicing installation (annually)	Medium
Life expectancy of major parts and/or installation	Dependent on weather conditions & unpredictable effects of marine degradation

2.4.8 Geothermal Power Generation from Ground Source Heat Pumps

Water pumped through a pipe buried in the ground can extract stored terrestrial heat energy and transfer it into a building for room heating and/or the provision of hot water. With regard to lighthouses, island-based stations could take advantage of existing groundwater storage tanks or lay pipes under courtyards etc to collect this heat energy. Additional power will be needed to operate the pump but if this was provided by solar voltaic panels and/or a wind turbine then the energy produced for building conditioning could be described as being 100% renewable.

Table 10: Evaluation of geothermal power generation systems

System Evaluation Criteria	System Characteristics
Power available from small to medium-sized systems	Estimated 1kW input to produce 5kW
Assessment of site suitability	Medium cost
Supplementary power (e.g. solar, wind turbine)	Necessary to power pump
Environmental considerations	Possible ground disturbance during installation
Heating	Constant heat provision
Planning & listed building consent implications	May be required
Initial cost of project and building preparation	High to Very High
Projected costs of servicing installation (annually)	Low
Life expectancy of major parts and/or installation	Guaranteed period

2.4.9 Conclusion

Despite the variety of energy systems available, the choice of the most appropriate system or combination of systems often necessitates a degree of compromise driven by financial constraints and site-specific factors. At most sites a hybrid system is adopted in which a variety of power generation systems are used for building conditioning.

Table 11: Comparative analysis of power generation systems (the lower the total score the lower the cost and impact and the greater the availability)

		Fossil Fuel Systems				Renewable Energy Systems					
Main Considerations	**Sub Headings**	**Grid Power**	**Gas Boiler**	**Cyclic Power**	**Oil Boiler**	**Solar Voltaic**	**Solar Thermal**	**Wind Turbine**	**Tidal Energy**	**Wave Energy**	**Geo-thermal Heat Pump**
Environment & Planning	Environmental Impact	8	8	8	12	12	5	4	5	6	5
	Planning	5	3	3	3	8	5	5	9	9	5
	Listed Building	1	5	5	2	8	5	5	3	1	1
	Navigation	1	1	1	1	1	1	5	5	12	1
Site Attributes	Space Availability	1	2	6	2	5	5	7	4	12	10
	Weather Patterns	1	1	1	1	4	4	8	12	12	1
	Turbulence	1	1	1	1	1	1	10	12	12	1
	Structural Analyses	1	2	5	2	2	2	5	12	12	2
	Building Preparation	2	8	10	5	5	5	5	14	14	8
Available Power	Direct	1	1	5	1	5	5	3	1	3	5
	Non-Direct	2	5	5	5	1	1	1	9	9	5
Costs	Project Costs	6	7	9	7	8	8	8	14	16	8
	Maintenance Costs	2	6	9	6	4	5	8	12	16	5
	Redundancy Costs	4	5	9	5	5	5	9	9	13	4
	Waste Disposal	5	12	9	12	5	5	8	8	12	5
Output	Direct Heat	9	5	9	5	9	4	8	8	8	5
	Electrical Power	1	5	6	5	5	4	5	5	7	16
	Supplementary Power Required	1	8	1	8	1	5	1	1	1	8
Conditioning Elements	Heat	1	1	5	5	8	4	5	5	5	4
	Dehumidification	1	5	8	5	8	16	8	8	8	12
	Mechanical Ventilation	1	5	8	5	8	16	8	8	12	10
	Positive Ventilation	1	8	5	8	12	12	5	8	8	6
Storage	Fuel	1	9	12	12	1	1	1	1	1	8
	Power	5	12	5	12	5	10	5	5	5	5
	Heat	5	8	8	8	5	5	5	10	10	5
Transport	Ship	1	12	12	12	2	1	2	1	12	1
	Helicopter	1	12	12	12	2	1	1	1	1	1
Total Score		**69**	**157**	**177**	**162**	**140**	**141**	**145**	**190**	**237**	**147**

Key to Scoring:

1–4 Low cost, low impact or high availability
5–8 Medium cost, medium impact or medium availability
9–12 High cost, high impact or low availability
13–16 Unacceptable cost or unacceptable impact

2.5 STATION EXPOSURE STATUS

Based on their location lighthouses can be described as being land-based, island-based or rock towers:

- **Land-based** – land-based stations are generally more accessible as they are part of the mainland and, as such, are connected to mains electricity. Consequently, more scope exists with regard to choice of building conditioning strategies and their feasibility. Such stations often comprise a variety of buildings including the tower, accommodation and other ancillary stores and outbuildings.
- **Island-based** – island-based stations tend to be built on island headlands or the island's highest point for good visibility. Most island-based stations comprise a tower and attached accommodation buildings and because of their off-shore status are reliant for building conditioning on power from generators and/or renewable energy sources. Access to such stations is by air or sea and consequently, strategies for building conditioning are necessarily constrained by the twin issues of power availability and access for equipment and maintenance.
- **Rock towers –** rock towers are built on a rocky outcrop or reef that is a shipping hazard. Rock towers are generally externally unpainted and all services are contained within the tower. Rock towers are exposed to the most extreme environmental conditions and, as such, are problematic when it comes to building conditioning.

The site of a station's location around the coastline of the United Kingdom and Ireland also means that they are exposed to a range of exposure conditions in terms of high wind speeds and driven rain. During prolonged spells of wind driven rain, masonry and concrete may become saturated and rain may penetrate cracks in a structure or through gaps (however small) around windows and door frames. The amount of rain received by a wall correlates fairly well with the product of rainfall and the component of the wind speed normal to the wall. The product of the mean annual wind speed is used as a driving rain index or factor of exposure.

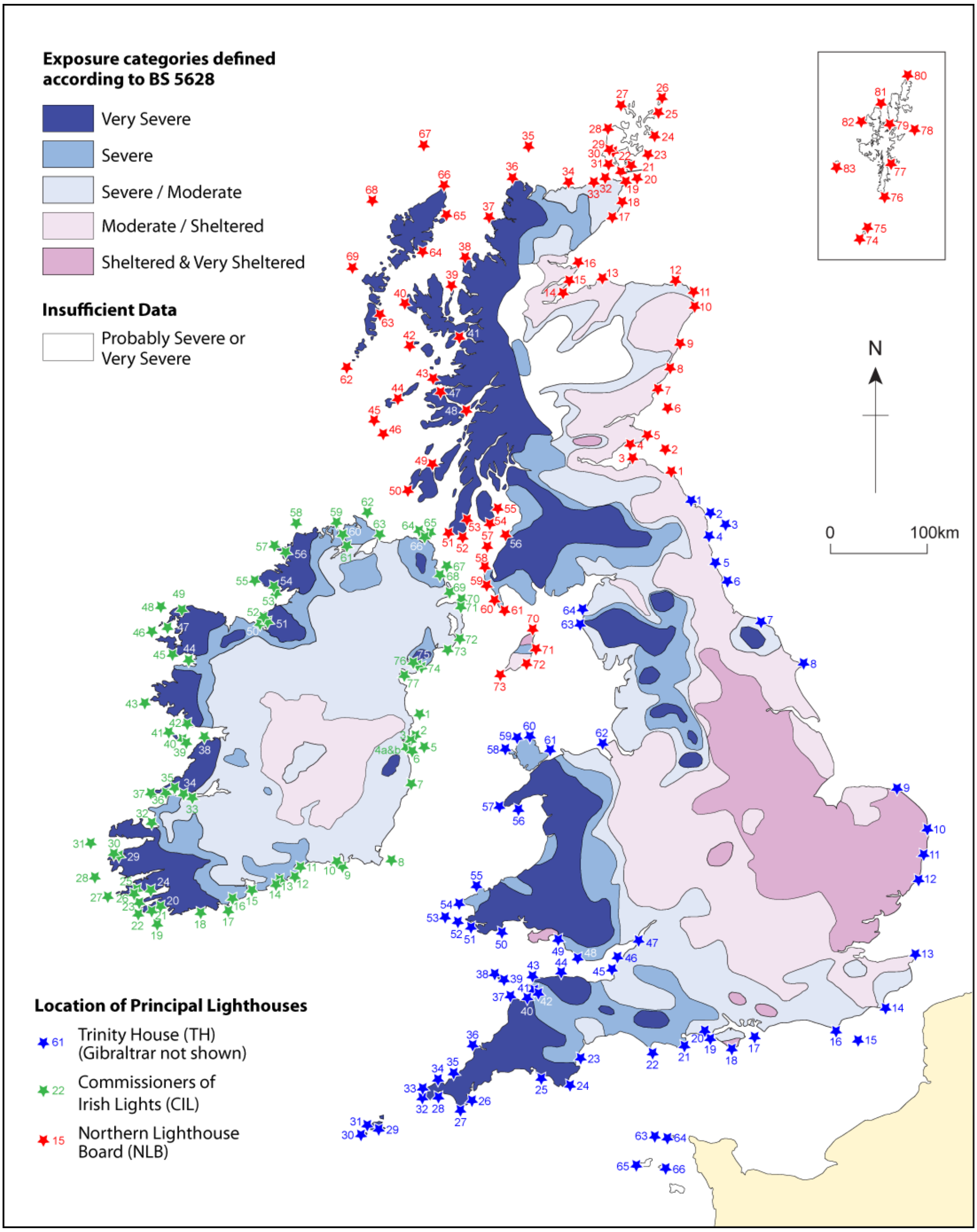
Table 12 shows detail of the wind driven rain exposure classification used to produce the map shown in Figure 8, which shows comparative exposure to driving rain in the area covered by the three GLAs. It is important to remember that this factor of exposure only serves as a rough guide but does provide a basis from which to categorise the location of lighthouses in terms of their exposure and the likely ingress of moisture whether this be rainwater, water vapour or sea spray and splash.

Table 12:Wind driven rain exposure categories

Exposure Category	L/m^2/SPELL*
Very Severe (VS)	>98
Severe (S)	68–123
Severe / Moderate (S/M)	46–85
Moderate / Sheltered (M/Sh)	29–58
Sheltered (& Very Sheltered) (Sh) & (Sh/VSh)	19–37

**Litres per square metre per period or sequence of periods of wind driven rain on a vertical surface*

Figure 8: Map showing location of principal lighthouses of the three GLAs and associated exposure categories throughout the United Kingdom and Ireland as defined by BS5628. (Key to lighthouse identification is provided in the following Tables 13–15)



A larger version of this map can be found in Appendix 5

Tables 13, 14 and 15 in the following pages contain detail of individual lighthouse stations for each of the three GLAs as shown in Figure 8. Keys to the abbreviations used for Exposure Category, Station Type, Power Generation and Conditioning Methods are outlined below:

Key to Exposure Category Abbreviations as shown in Figure 8

Abbreviation	Category Description
VS	Very Severe
S	Severe
S/M	Severe/Moderate
M/Sh	Moderate/Sheltered
Sh/VSh	Sheltered & Very Sheltered

Where exposure data are unavailable the exposure category is assumed to be Severe or Very Severe (S/VS)

Key to Station Type

Station Category	Description
Land	Station connected to the mainland
Island	Station located on an island
Rock	Station built on a pinnacle of rock

Key to Power Generation Abbreviations

Abbreviation	Power Source	Description
M	Mains Electricity	MF0 = Mains power, Float battery without standby Generator MFG = Mains power, Float battery with standby Generator MAC = Mains power, AC light with standby Generator
S	Solar Power	SFT = Solar power, Float battery, Telemetry SFP = Solar power, Float battery, Purplefinder
S/H	Solar Power Hybrid	SFG = Solar power, Float battery with standby Generator (automatic) SFA = Solar power, Float battery with Generator (manual start) SFH = Solar power / Wind / Diesel Hybrid, Float battery
C/C (CCF)	Diesel Generator	Cycle Run Generation
C/R	Diesel Generator	Constant Run Generation (24/7)

Key to Conditioning Methods

Abbreviation	Conditioning Method(s)
V	Ventilation
NR	Not Required
SH	Storage Heaters
SH+V	Storage Heaters + Ventilation
C/R+CH+V	Constant Running Generation + Central Heating + Ventilation
V+HvE	Ventilation + Heating for visiting Engineers
Oil/CH+SH	Oil Central Heating + Storage Heaters
V+W/SH	Ventilation + Wind / Storage Heaters
V+Cyc/SH+HvE	Ventilation + Cyclic / Storage Heating + heating for visiting Engineers
Oil/CH+InvH	Oil Central Heating + DC Inverters supplying Heaters in domestic areas
Oil/CH+SH+V+HvE	Oil Central Heating + Storage Heaters + Ventilation + Heating for visiting Engineers
SH+D	Storage Heaters + Dehumidification
+vePV	Positive Pressure Ventilation

Table 13: Information for Trinity House Lighthouses shown in Figure 8

Map No.	Name	Type of Station	Location	Exposure Category	Power Generation	Conditioning Methods	Conditioning Issues
1	Heugh Hill	Land	55° 40’.1 N 01° 47’.9 W	M/Sh	S	NR	N/A
2	Guile Point	Land	55° 39’.5 N 01° 47’.5 W	M/Sh	S	NR	N/A
3	Longstone	Island	55° 38'.63 N 01° 36'.58 W	M/Sh	C/R	C/R+CH+V	Historic salt ingress in tower
4	Bamburgh	Land	55° 36'.97 N 01° 43'.35 W	M/Sh	M	SH+V	None
5	Farne	Island	55 36'.93 N 01 39'.25 W	M/Sh	S/H	V	Ventilation introduced (tower only - rest of property sold off to the National Trust)
6	Coquet	Island	55 20.0 N 01 32.2 W	M/Sh	S/H	V+HvE	C/R removed 2007 - heating to domestic areas only
7	Whitby	Land	54° 28'.67 N 00° 34'.00 W	S/M	M	SH	Some internal salts due to historic water ingress
8	Flamborough	Land	54° 06'.98N 00° 04'.96W	M/Sh	M	SH	Some internal salts due to historic water ingress
9	Cromer	Land	52° 55'.45 N 01° 19'.10 E	Sh/VSh	M	SH	High humidity in basement bedroom of cottage due to lack of ventilation
10	Lowestoft	Land	52 29'.2 N 01 45'.5 E	Sh/VSh	M	SH	None
11	Southwold	Land	52° 19'.60 N 01° 41'.00 E	Sh/VSh	M	SH	None
12	Orfordness	Land	52° 05'.0 N 01° 34'.6 E	Sh/VSh	M	SH+V	Historic salts on ground floor staircases due to cellar being blocked up
13	North Foreland	Land	51 22'.5 N 1 26'.8 E	M/Sh	M	V	External cement render (cracking and water ingress - now being vented
14	Dungeness	Land	50° 54'.77 N 00° 58'.70 E	S/M	M	SH	Historic ingress of water through ground floor roof now resolved
15	Royal Sovereign	Rock	50° 43'.40 N 00° 26'.13 E	S/M	S/H	V	Lack of ventilation periods of high humidity
16	Beachy Head	Rock	50° 44'.0 N 00° 14'.50 E	S/M	M	V+HvE	Water ingress through lantern glazing, subject to high humidity
17	Nab Tower	Rock	50° 40'.05 N 00° 57'.07 W	S/M	S/H	NR	Cavernouse steel structure in poor condition - no conditioning
18	St. Catherine's	Land	50° 34'.50 N 01° 17'.80 W	Sh/VSh	M	SH	None
19	Needles	Rock	50 39'.70 N 01 35.42 W	S/M	M	SH	Historic water ingress through crack in masonry - now resolved

Map No.	Name	Type of Station	Location	Exposure Category	Power Generation	Conditioning Methods	Conditioning Issues
20	Hurst Point	Land	50 42'. 44 N 01 32'.94 W	S/M	C/C	V	High humidity - lantern vents reopened and low level ventilation introduced
21	Anvil Point	Land	50° 35'.48 N 01° 57'.51 W	S	M	SH+V	High humidity due to the lack of ventilation
22	Portland Bill	Land	50° 30'.82 N 02° 27'.30 W	S	M	SH+V	Historical high humidity partly resolved by a breathable internal coating
23	Berry Head	Land	50 24.0 N 03 28.9 W	S	M	SH	None
24	Start Point	Land	50° 13'.30 N 03° 38'.47 W	VS	M	SH	Water ingress through lantern roof and sector light window - remedy and monitor
25	Eddystone	Rock	50° 10'.80 N 04° 15'.90 W	VS	S/H	V+HvE	Limited heating for visiting engineers only
26	St. Anthony's	Land	50 08'.4 N 05 00'.9 W	VS	M	SH	None
27	Lizard	Land	49° 57'.58 N 05° 12'.07 W	VS	M	Oil/CH+SH	None
28	Tater Du	Land	50° 03'.12 N 05° 34'.60 W	VS	M	SH	None
29	Penninis	Land	49° 54'.2 N 06° 18'.2 W	VS	M	None	N/A
30	Bishop Rock	Rock	49 52.3 N 06 26.7 W	VS	C/C	V+HvE	Limited heating for visiting engineers only
31	Round Island	Island	49° 58.70'N 006° 19.35W	VS	S/H	V+HvE	Limited heating for visiting engineers only - signs of humidity
32	Wolf Rock	Island	49° 56'.72 N 05° 48'.50 W	VS	S/H	V+HvE	Limited heating for visiting engineers only - signs of humidity
33	Longships	Rock	50° 03.97'N 005° 44.75'W	VS	S/H	Oil/CH+Inv/H	Monitored heating and humidity control
34	Pendeen	Land	50° 9'.85 N 05° 40'.20 W	VS	M	SH	None
35	Godrevy	Island	50 14'.5 N 05 23'.9 W	VS	S/H	V	Agreed ventilation and internal decoration to become delaminated naturally
36	Trevose Head	Land	50° 32'.92 N 05° 02'.07 W	VS	M	SH	Structural cracks in terraced ground floor wall - water and salts ingress
37	Hartland Point	Land	51 01. 3 N 04 31. 4 W	VS	M	SH+V	Cracks in gallery corbel - repaired but historic water ingress has introduced salts
38	Lundy North	Island	51° 12'.1 N 04° 40'.6 W	VS	S/H	V	Weather & water tight only - high internal humidity
39	Lundy South	Island	51° 09'.7 N 04° 39'.3 W	VS	S/H	V+W/SH	Redundant accommodation vented and heated by power from wind generator - tower vented - lantern glazing leaks
40	Crow Point	Land	51° 03.9 N 04° 11.3 W	S	S	NR	N/A

Map No.	Name	Type of Station	Location	Exposure Category	Power Generation	Conditioning Methods	Conditioning Issues
41	Instow Front	Land	51° 03.62 N 04° 10.66 W	S	M	SH	None
42	Instow Rear	Land	51° 03.52 N 04° 10.36 W	S	M	SH	None
43	Bull Point	Land	51° 11'.95 N 4° 12'.05 W	VS	M	SH	None
44	Lynmouth Foreland	Land	51° 14'.7 N 03° 47'.1 W	VS	M	SH	Historical lantern roof issues - water ingress - major works required
45	Flatholm	Island	51° 22'.50 N 03° 07'.00 W	S/M	S/H	V	Limited ventilation suffers from high humidity
46	Monkstone	Rock	51° 24.89 N 03° 06.01 W	S/M	S	N/A	None
47	Blacknore Point	Land	51 29.1 N 02 48. 0 W	M/Sh	M	V	N/A
48	Nash Point	Land	51° 24'.00 N 03° 33'.05 W	S	M	SH	Operational tower - historic water ingress now resolved - all internal coatings removed
49	Mumbles	Island	51 33'.99 N 03 58'.21 W	S	S/H	V	Condensation issues in lantern
50	Caldey Island	Island	51° 37'.86 N 04° 41'.00 W	VS	S/H	SH+V	None
51	St. Ann's Head	Land	51° 40'.83 N 05° 10'.38 W	VS	M	SH	Tower - none / Cottages weather and water tight suffers from humidity and minor water ingress
52	Skokholm	Island	51° 41'.61 N 05° 17'.15 W	VS	S/H	Oil/H+V	Limited heating for visiting engineers only - historic issues with water ingress and humidity
53	Smalls	Rock	51° 43'.23 N 05° 40'.10 W	VS	S/H	V+HvE	Limited heating for visiting engineers only
54	South Bishop	Island	51° 51'.15 N 5° 24'.65 W	VS	S/H	Oil/H+V	Heating on limited time 2hours in 24 + Limited heating for visiting engineers
55	Strumble Head	Island	52 01'. 75 N 05 04'. 36 W	S	M	SH	None - recent reglazing of lantern
56	St. Tudwal's	Island	52° 47'.9 N 04° 28'.2 W	VS	S/H	V	Ventilation of tower with some salts
57	Bardsey	Island	52° 44'.97 N 04° 47'.95 W	VS	C/R	Oil/H+V	Tower - Saponification of internal decoration, decoration to be removed and ventilation introduced (2009)
58	South Stack	Island	53 18'.4 N 04 41'.9 W	S	M	SH+V	Tower - some salts internal decoration changed to breathable system, ventilation required
59	Skerries	Island	53 25.'3 N 4 36'.4 W	S	S/H	V+Cyc/H+HvE	Internal conditioning to be upgraded due to poorly controlled heating system
60	Point Lynas	Land	53 25'.O N 04 17'.3 W	S	M	SH	None

Map No.	Name	Type of Station	Location	Exposure Category	Power Generation	Conditioning Methods	Conditioning Issues
61	Trwyn Du	Rock	53° 18'.80 N 04° 02'.40 W	S	S/H	V	Generally in good decorative order - ventilation only
62	Hilbre Island	Island	53 23.0 N 03 13.7 W	M/Sh	S	NR	N/A
63	St. Bees	Land	54° 30'.82 N 03° 38'.10 W	VS	M	SH	Generally good some salts due to historic water ingress
64	Maryport	Land	54 43'.10 N 03 30'.50 W	S/M	S	NR	N/A
65	Casquets	Land	49 43'.4 N 02 22'.7 W	VS	C/R	C/R+CH+V	Tower - Saponification of internal decoration, decoration to be removed and ventilation introduced (2013)
66	Alderney	Land	49° 43'.82 N 02° 09'.78 W	S	M	SH+D	Salts due to historic water ingress through cracks in render and window reveals
67	Les Hanois	Rock	49 26.2 N 02 42.1 W	VS	S/H	V+HvE	High humidity and low level salt ingress - intention to ventilate
68	Sark	Land	49° 26'.26 N 02° 20'.67 W	S	M	SH	None

N.B. Europa Point (Gibraltar) is not included in Table 13

Table 14: Information for lighthouses run by the Commissioners of Irish Lights shown in Figure 8

Map No.	Name	Type of Station	Location	Exposure Category	Power Generation	Conditioning Methods (Tower)	Conditioning Methods (Accommodation)	Conditioning Issues
1	Rockabill	Island	53°35.811'N 6°00.297'W	S/M	S/H	None	S/H+Oil C/H	
2	Howth	Land	53°23.643'N 6°04.020'W	S/M	M	None	N/A	
3	Baily	Land	53°21.691'N 6°03.158'W	S/M	M	S/H	Oil C/H	
4	Dun Laoghaire East	Land	53°18.151'N 6°07.626'W	S/M	M	None	S/H	
5	Dun Laoghaire West	Land	53°18.151'N 6°07.626'W	S/M	S	None	N/A	
6	Kish	Rock	53°18.650'N 5°55.542'W	S/M	C/C	C/H	C/H	
7	Muglins	Rock	53°16.5'N 6°4.5'W	S/M	S	N/A	N/A	
8	Wicklow Head	Land	52°57.9'N 5°59.8'W	S/M	M	D	Cold snap	
9	Tuskar Rock	Rock	52°12.2'N 6°12.4'W	S/M	C/C	Hot Air	Oil C/H	
10	Hook Head	Land	52°07.424'N 6°55.770'W	S/M	M	None	Cold snap	
11	Dunmore East	Land	52°08.935'N 6°59.337'W	S/M	M	None	S/H	
12	Ballinacourty Point	Land	52°04.688'N 7°33.182'W	S	M	None	El/H	
13	Mine Head	Land	51°59.556'N 7°35.225'W	S	M	S/H	S/H	
14	Youghal	Land	51°56.5'N 7°50.5'W	S	M	S/H	N/A	
15	Ballycotton	Island	51°49.522'N 7°59.169' W	S	S/H	D	Oil C/H+S/H	
16	Roches Point	Land	51°47.6'N 8°15.3'W	S	M	None	Cold snap	
17	Charlesfort	Land	51°41.752'N 8°29.984'W	S	M	None	N/A	
18	Old Head of Kinsale	Land	51°36.287'N 8°32.018'W	S	M	None	HvE	
19	Galley Head	Land	51°31.798'N 8°57.210'W	VS	M	None	HvE	
20	Fastnet	Rock	51°23.358'N 9°36.178'W	VS	C/R	Dgen Secondary	Dgen Secondary C/H	
21	Copper Point	Land	51°30.250'N 9°32.063'W	VS	M	N/A	N/A	
22	Crookhaven	Land	51°28.593'N 9°42.273'W	VS	M	None	None	
23	Mizen Head	Land	51°26.991'N 9°49.225'W	VS	M	N/A	N/A	
24	Sheeps Head	Land	51°32.591'N 9°50.923'W	VS	M	Cold snap	N/A	
25	Roancarrigmore	Island	51°39.180'N 9°44.820'W	VS	C/R	None	N/A	
26	Castletownbere Dir Light	Land	51°38.792'N 9°54.312'W	VS	M	Cold snap	N/A	
27	Ardnakinna	Land	51°37.104'N 9°55.092'W	VS	M	None	N/A	
28	Bull Rock	Island	51°35.521'N 10°18.073'W	VS	S/H	None	+vePV (Wallas)	
29	Skelligs	Island	51°46.108'N 10°32.519'W	VS	S/H	None	+vePV (2xWallas)	

Map No.	Name	Type of Station	Location	Exposure Category	Power Generation	Conditioning Methods (Tower)	Conditioning Methods (Accommodation)	Conditioning Issues
30	Valentia	Land	51°55.464'N 10°18.352' W	VS	M	None	N/A	
31	Cromwell Point	Land	51°56.022'N 10°19.280'W	VS	M	D	D	
32	Inishtearaght	Rock	52°04.541'N 10°39.677'W	VS	S/H	None	N/A	
33	Little Samphire Island	Island	52°16.254'N 9°52.909'W	S		D	None	
34	Scattery Island	Island	52°36.347'N 9°31.067'W	S/M	S	None	N/A	
35	Corlis Point	Land	52°37.100'N 9°36.363'W	VS	M	N/A	N/A	
36	Kilcredaun Head	Land	52°34.809'N 9°42.613'W	VS	M	S/H	S/H	
37	Loophead	Land	52°33.672'N 9°55.938'W	VS	M	None	Oil C/H	
38	Blackhead Clare	Land	53°09.253'N 9°15.839'W	VS	N/A	None	N/A	
39	Inisheer	Island	53°02.797'N 9°31.613'W	VS	M	None	N/A	
40	Straw island	Island	53°07.065'N 9°37.840'W	VS	S/H	None	HvE	
41	Eeragh	Island	53°08.909'N 9°51.402'W	VS	S/H	None	W/P H	
42	Cashla Bay	Land	53°15.834'N 9°33.982'W	VS	M	Cold snap	N/A	
43	Slyne Head	Island	53°23.997'N 10°14.051'W	VS	S/H	None	Oil C/H	
44	Inishgort	Island	53°49.594'N 9°40.259'W	VS	S	None	N/A	
45	Achillbeg	Land	53°51.509'N 9°56.835'W	VS	M	Cold snap	N/A	
46	Blackrock Mayo	Rock	54°04.055'N 10°19.230'W	VS	S/H	None	HvE	
47	Blacksod	Land	54°05.923'N 10°03.628'W	VS	M	S/H	S/H	
48	Eagle Island	Island	54°17.022'N 10°05.564'W	VS	S/H	None	Oil C/H	
49	Broadhaven	Land	54°16.065'N 9°53.330'W	VS	M	None	N/A	
50	Blackrock Sligo	Rock	54°18.460'N 8°37.059'W	S	S	None	N/A	
51	Oyster Island	Island	54°18.122'N 8°34.273'W	VS	S	None	N/A	
52	Lower Rosses	Island	54°19.726'N 8°34.408'W	VS	M	N/A	N/A	
53	St. John's Point Donegal	Land	54°34.162'N 8°27.657'W	VS	M	None	N/A	
54	Rotten Island	Island	54°36.879'N 8°26.435'W	VS	M	None	N/A	
55	Rathlin O Birne	Island	54°39.816'N 8°49.951'W	VS	S/H	None	N/A	
56	Ballagh Rocks	Rock	54°59.963'N 8°28.839'W	VS	B	N/A	N/A	
57	Aranmore	Land	55°00.903"N 8°33.666'W	VS	M	S/H	N/A	
58	Tory Island	Island	55°16.357'N 8°14.964'W	VS	C/C	None	S/H	
59	Fanad Head	Land	55°16.575'N 7°37.921'W	S	M	None	S/H	
60	Dunree	Land	55°11.888'N 7°33.250'W	S	M	None	N/A	
61	Buncrana	Land	55°07.604'N 7°27.881'W	S/M	M	N/A	N/A	

Map No.	Name	Type of Station	Location	Exposure Category	Power Generation	Conditioning Methods (Tower)	Conditioning Methods (Accommodation)	Conditioning Issues
62	Inishtrahull	Island	55°25.864'N 7°14.628'W	S	S/H	None	Oil C/H+ +vePV (EnviroVent)	
63	Inishowen	Land	55°13.6'N 6°55.7'W	S	M	None	Oil C/H	
64	Rathlin West	Land	55°18.052'N 6°16.815'W	VS	M	El/H+D	N/A	
65	Rathlin East	Land	55°18.111'N 6°10.313'W	VS	M	S/H+D	Oil C/H	
66	Rue Point	Land	55°15.533'N 6°11.474'W	VS	M	None	N/A	
67	Maidens	Island	54°55.748'N 5°43.709'W	S	C/C	None	S/H	
68	Chaine Tower	Land	54°51.270'N 5°47.878'W	S	M	None	N/A	
69	Blackhead Antrim	Land	54°46.016'N 5°41.338'W	S/M	M	S/H	El/ H	
70	Mew Island	Island	54°41.923'N 5°30.824'W	S/M	C/R	S/H	Oil C/H+S/H	
71	Donaghadee	Land	54°38.707'N 5°31.860'W	S/M	M	SH+V	El/H	
72	Angus Rock	Rock	54°19.843'N 5°31.520'W	S/M	S	None	N/A	
73	St. John's Point Down	Land	54°13.605'N 5°39.611'W	S/M	M	None	S/H	
74	Haulbowline	Rock	54°01.196'N 6°04.740'W	S/M	C/R	None	N/A	
75	Vidal Bank	Rock	54°01.799'N 6°05.433'W	S/M	S	N/A	N/A	
76	Green Island	Rock	54°01.959'N 6°05.754'W	S/M	S	N/A	N/A	
77	Dundalk	Land	53°58.560'N 6°17.714'W	S/M	M	None	N/A	

Table 15: Information for lighthouses run by the Northern Lighthouse Board shown in Figure 8

Map No.	Name	Type of Station	Location	Exposure Category	Power Generation	Conditioning Methods	Conditioning Issues
1	St. Abbs Head	Land	55° 55.0'N 02° 08.3'W	M/Sh	M	SH+D	Good condition
2	Isle of May	Island	56° 11.14'N 02° 33.45'W	M/Sh	C/C	Cyc/SH+HvE	-
3	Fidra	Island	56° 04.40'N 02° 47.10'W	M/Sh	M	SH+D	Fair condition
4	Elie Ness	Land	56° 11.00'N 02° 48.80'W	M/Sh	M	SH+D	Fair condition
5	Fife ness	Land	56° 16.7'N 02° 35.1'W	M/Sh	M	SH+D	Good condition
6	Bell Rock	Rock	56° 26.1'N 02° 23.1'W	M/Sh	S/H	Cyc/SH+HvE	Fair condition
7	Scurdie Ness	Land	56° 42.1'N 02° 26.1'W	M/Sh	M	SH+D	-
8	Tod Head	Land	56° 53.0'N 02° 12.8'W	M/Sh	M	SH+D	Good condition
9	Girdle ness	Land	57° 08.3'N 02° 02.8'W	M/Sh	M	SH+D	Good condition
10	Buchan Ness	Land	57° 28.2' N 01° 46.4'W	M/Sh	M	SH+D	Good condition
11	Rattray head	Rock	57° 36.6'N 01° 48.9'W	S/M	M	SH+D	-
12	Kinnaird Head	Land	57° 41.9'N 02° 00.1'W	S/M	M	NR	Fair condition
13	Covesea Skerries	Land	57° 43.5'N 3° 20.2'W	M/Sh	M	SH+D	Good condition
14	Chanonry	Land	57° 34.5'N 04° 05.4'W	M/Sh	M	SH+D	-
15	Cromarty	Land	57° 41.0'N 04° 02.1'W	M/Sh	M	SH+D	Good condition
16	Tarbat Ness	Land	57° 51.9'N 03° 46.5'W	M/Sh	M	SH+D	-
17	Clythness	Land	58° 18.7'N 03° 12.6'W	S/M	M	SH+D	-
18	Noss Head	Land	58° 28.8'N 03° 03.0'W	S/M	M	SH+D	-
19	Duncansby Head	Land	58° 38.6'N 03° 01.4'W	S/M	M	SH+D	-
20	Pentland Skerries	Island	58° 41.4'N 02° 55.4'W	S/VS	C/C	Cyc/SH+HvE	-
21	Stroma	Island	58° 41.8'N 03° 07.0'W	S/VS	C/C	Cyc/SH+HvE	-
22	Cantick Head	Land	58° 47.2'N 03° 07.8'W	S/VS	M	SH+D	-
23	Copinsay	Island	58° 53.8'N 02° 40.2'W	S/VS	C/C	Cyc/SH+HvE	-
24	Auskerry	Island	59° 01.6'N 02° 34.2'W	S/VS	S/H	Cyc/SH+HvE	-
25	Start Point	Land	59° 16.7'N 02° 22.5'W	S/VS	S/H	Cyc/SH+HvE	-
26	North Ronaldsay	Land	59° 23.4'N 02° 22.8'W	S/VS	C/C	Cyc/SH+HvE	Good condition
27	Noup Head	Land	59° 19.9'N 03° 04.0'W	S/VS	S/H	-	Good condition
28	Brough of Birsay	Land	59° 08.2'N 03° 20.3'W	S/VS	S/H	Cyc/SH+HvE	-
29	Hoy Sound High	Land	58° 56.5'N 03° 18.4'W	S/VS	M	SH+D	-
30	Hoy Sound Low	Land	58° 56.2'N 03° 16.3'W	S/VS	M	SH+D	-
31	Tor Ness	Land	58° 46.7'N 03° 17.6'W	S/VS	M	SH	-
32	Dunnet Head	Land	58° 40.3'N 03° 22.4'W	S/M	M	SH+D	-

Map No.	Name	Type of Station	Location	Exposure Category	Power Generation	Conditioning Methods	Conditioning Issues
33	Holborn Head	Land	58° 36.9'N 03° 32.4'W	S/M	M	SH+D	Poor condition, unused buildings - light discontinued
34	Strathy Point	Land	58° 36.1'N 04° 00.9'W	S/M	M	SH+D	-
35	Sule Skerry	Island	59° 05.0'N 04° 24.3'W	VS	C/C	Cyc/SH+HvE	-
36	Cape Wrath	Land	58° 37.6'N 04° 59.9'W	VS	C/C	Cyc/SH+HvE	-
37	Stoer Head	Land	58° 14.4'N 05° 24.0'W	VS	M	SH+D	-
38	Rubh Re	Land	57° 51.4'N 05° 48.6'W	VS	M	SH+D	-
39	Rona	Island	57° 34.7'N 05° 57.5'W	VS	S	-	-
40	Neist Point	Land	57° 25.4'N 06° 47.2'W	VS	M	SH+D	Fair condition
41	Ornsay	Island	57° 08.6'N 05° 46.4'W	VS	M	SH+D	Fair condition
42	Hyskeir	Island	56° 58.2'N 06° 40.9'W	VS	C/C	Cyc/SH+HvE	-
43	Ardnamurchan	Land	56° 43.6'N 06° 13.4'W	VS	M	SH+D	-
44	Scarinish	Land	56° 30.0'N 06° 48.2'W	VS	M	SH+D	-
45	Skerryvore	Rock	56° 19.4'N 07° 06.9'W	VS	C/C	Cyc/SH+HvE	-
46	Dubh Artach	Rock	56° 08.0'N 06° 37.9'W	VS	S/H	Cyc/SH+HvE	-
47	Rubha Nan Gall	Land	56° 38.3'N 06° 03.9'W	VS	S	-	-
48	Lismore	Island	56° 27.4'N 05° 36.4'W	VS	S	Cyc/SH+HvE	Good condition
49	Ruvaal	Island	55° 56.2'N 06° 07.3'W	VS	M	SH+D	-
50	Rinns of Islay	Island	55° 40.4'N 06° 30.8'W	VS	M	SH+D	-
51	Mull of Kintyre	Land	55° 18.6'N 05° 48.1'W	VS	M	SH+D	Good condition
52	Sanda	Island	55° 16.5'N 05° 34.9'W	VS	S	Cyc/SH+HvE	-
53	Davaar	Island	55° 25.7'N 05° 32.4'W	VS	M	SH+D	Good condition
54	Pladda	Island	55° 25.5'N 05° 07.3'W	VS	C/C	Cyc/SH+HvE	-
55	Holy Island (outer)	Island	55° 31.0'N 05° 03.6'W	VS	M	SH+D	Fair condition
56	Turnberry	Land	55° 19'N 04° 50'W	S	M	SH+D	-
57	Ailsa Craig	Island	55° 15.1'N 05° 06.4'W	VS	S/H	Cyc/SH+HvE	-
58	Corsewall	Land	55° 00.5'N 05° 09.5'W	S	M	SH+D	Good condition
59	Killantringan	Land	54° 51.7'N 05° 08.7'W	S	M	SH+D	Fair condition
60	Crammag Head	Land	54° 39.9'N 04° 57.8'W	S	M	SH+D	Fair condition
61	Mull of Galloway	Land	54° 38.1'N 04° 51.4'W	S	M	SH+D	Good condition
62	Barra Head	Island	56° 47.1'N 07° 39.2'W	VS	C/C	Cyc/SH+HvE	-
63	Ushenish	Island	57° 17.9'N 07° 11.5'W	VS	S	Cyc/SH+HvE	-
64	Eilean Glas	Island	57° 51.4'N 06° 38.5'W	VS	M	SH+D	-
65	Tiumpan Head	Land	58° 15.6'N 06° 08.3'W	VS	M	SH+D	-
66	Butt of Lewis	Land	58° 31.0'N 06° 15.7'W	VS	M	SH+D	-

Map No.	Name	Type of Station	Location	Exposure Category	Power Generation	Conditioning Methods	Conditioning Issues
67	North Rona	Island	59° 07.3'N 05° 48.8'W	VS	C/C	Cyc/SH+HvE	-
68	Flannan Islands	Island	58° 17.3'N 07° 35.4'W	VS	S/H	Cyc/SH+HvE	-
69	Haskeir	Island	56° 58.2'N 06° 40.9'W	VS	S/H	NR	Good condition
70	Point of Ayre	Land	54° 24.9'N 04° 22.1'W	Sh/VSh	M	SH+D	-
71	Maughold Head	Land	54° 17.7'N 04° 18.4'W	S	M	SH+D	-
72	Douglas Head	Land	54° 08.6'N 04° 27.9'W	M/Sh	M	SH+D	-
73	Calf of Man	Island	54° 03.2'N 04° 49.6'W	M/Sh	C/C	-	-
74	Fair Isle South	Island	59° 30.9'N 01° 39.0'W	S/VS	C/C	Cyc/SH+HvE	Fair condition
75	Fair Isle North	Island	59° 33.2'N 01° 36.5'W	S/VS	C/C	Cyc/SH+HvE	Redundant rooms, with no heating or decent ventilation, giving rise to excessive condensation
76	Sumburgh Head	Land	59° 51.3'N 01° 16.3'W	S/VS	M	SH+D	-
77	Bressay	Land	60° 07.2'N 01° 07.2'W	S/VS	M	SH+D	-
78	Out Skerries	Island	60° 25.5'N 00° 43.5'W	S/VS	S/H	Cyc/SH+HvE	Good condition
79	Firths Voe	Land	60° 27.2'N 01° 10.6'W	S/VS	M	SH+D	-
80	Muckle Flugga	Island	60° 51.3'N 00° 53.0'W	S/VS	C/C	Cyc/SH+HvE	Fair condition
81	Point of Fethaland	Land	60° 38.1'N 01° 18.7'W	S/VS	M	SH+D	-
82	Esha Ness	Land	60° 29.3'N 01° 37.6'W	S/VS	M	SH+D	Fair condition
83	Foula	Island	60° 06.8'N 02° 03.7'W	S/VS	S/H	NR	-

2.6 BUILDING CONDITIONING CASE STUDIES

The following case studies from the three GLAs give examples of different approaches to off-shore building condition management where the restrictions on excess power availability increases reliance on energy from renewable energy sources. Examples are given from island-based and rock tower stations.

2.6.1 Island-Based Lighthouses

Lundy South Lighthouse (TH) - Lundy South is located approximately 16km off the north Devon coast in the Bristol Channel (TH site 39 in Figure 8). In terms of high winds and driven rain, Lundy South is described as being in the 'Very Severe' exposure category (Figure 9a). The station was constructed in 1897 and converted to solar power in 1995. Since automation the accommodation buildings have been badly affected by condensation and mould growth. The severity of the situation necessitated the introduction of heating but the solar arrays alone could not provide sufficient energy and consequently a Proven WT2500 wind turbine was installed to provide sufficient additional power for storage heaters on permanent load within the accommodation (Figure 9b). In addition to the heaters, extra passive trickle-ventilation was facilitated with the fitting of baffled vents at high and low levels in each room throughout the building.

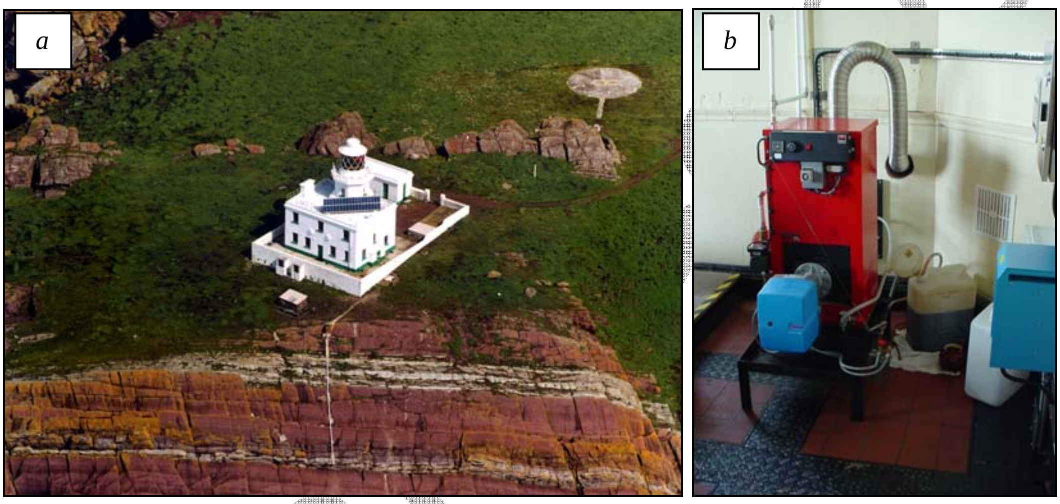
The calculated energy requirement for heating of the building was 2.0kW, which was covered by the 2.5kW wind turbine. The wind turbine became fully operational in 2002 and in the following years from 2002-2006 mould growth ceased to be a problem providing evidence that the combination of trickle ventilation and heating was sufficient to significantly improve the internal condition of the building.

Figure 9a: Lundy South lighthouse

Figure 9b: Combination of a solar array and a Proven WT2500 wind turbine at Lundy South

***Skokholm Lighthouse (TH)* –** Skokholm was built in 1916 and converted to solar power in 1998. Skokholm Island is located approximately 3km off the Pembrokeshire coast and marks the approaches to Milford Haven (TH site 52 in Figure 8). Skokholm's conditions of exposure to wind and driven rain are described as being 'Very Severe'. The station comprises an 18m high octagonal masonry tower mounted on a rectangular building (Figure 10a). The solar panels generate sufficient power for the Navigation Aids with a diesel generator activated for additional power when personnel are on station.

Initially building conditioning was reliant on a passive ventilation system but this proved to be insufficient with the spread of mildew and mould. To address this situation an oil-fired 'Kabola' boiler was installed and this provided two hours of heating per day (Figure 10b). Whilst the standard of building conditioning is not 'ideal', it has improved since the introduction of heating and is now of sufficient quality for personnel required to stay overnight. On-going monitoring of the internal condition of the structure will inform future decisions regarding any modification of the heating regime.



Figures 10: (a) Skokholm lighthouse and, (b) the 'Kabola' boiler providing additional heating for conditioning of accommodation

***Inishtrahull and Bull Rock Lighthouses (CIL)* –** Accommodation buildings at two CIL stations were selected for monitoring and trialling of building conditioning systems. Inishtrahull Lighthouse (CIL site 62 in Figure 8) is located on an island off the north coast of Ireland where the weather tends to be relatively cold and dry. Bull Rock Lighthouse (CIL site 28 in Figure 8) is an island station located off the southwest coast of Ireland where the accommodation building is sited above a blowhole with the result that it is continually in the salt spray zone. Internal and external humidity and temperature sensors connected to data loggers were installed at both sites with sensors installed in the front and rear of both buildings as this allowed assessment of any passive solar heat gain.

Each building has an internal volume of approximately 350m³ and to get the required air changes per hour it was estimated that each of the units should have an output of 175m³. As there was no spare energy available at either of these solarised stations any equipment installed had to have low energy requirements. Following a review of the building conditioning equipment that was commercially available two different systems were identified as fulfilling requirements with regard to energy input and ventilation output. Installation of these units also required internal doors to be left open to facilitate airflow.

- ***Inishtrahull Lighthouse*** – An EnviroVent Positive Pressure Ventilation unit was installed at Inishtrahull (Figure 11) with the power needed to operate it generated by a specially installed Air X Marine wind turbine that maintained a charged bank of batteries. As the selected building had a flat roof, the actual positive pressure ventilation unit was installed at ceiling level on the upper floor with an air intake filter fitted to remove salt and moisture in the in-coming air. Unfortunately, the Air X Marine wind turbine failed after a couple of months and was not replaced so the lifespan of the EnviroVent unit which is guaranteed by the manufacturer for 5 years or its success in terms of building conditioning could not be fully determined. During the short time that the EnviroVent Unit was in operation, some visiting personnel reported that the air delivered from the unit was cold and they requested that the unit be switched off when personnel were on station. However, anecdotal evidence indicated that despite the brief period of operation building conditioning did improve with a reduction in mould growth and a perceived reduction in damp.

Figure 11: Inishtrahull Lighthouse complex

- ***Bull Rock Lighthouse*** – At Bull Rock (Figure 12) a Wallas 30D Positive Pressure Ventilation and Heating Unit was installed near a window in the accommodation building so that the balanced flue could be mounted within the window itself. A filter was also fitted on this unit to remove salt and moisture from the air intake. Power was supplied to the battery bank by solar panels. The positive pressure/heating unit was modified so that the 3kW heater unit functioned only when the relative humidity (RH) exceeded 80%. The RH figure of 80% was chosen as an analysis of the data from the stations showed that when the RH exceeded 80% the difference between the air temperature and the dew point was less than 5°C, and it is generally accepted that condensation tends to occur when the difference between air temperature and dew point is less than 3–5°C. At Bull Rock because of the location of a blowhole in front of the accommodation buildings and the almost continuous exposure to salt spray, salt accumulation and moisture penetration is a major problem around the front windows internally as well as externally. In addition, damp has always affected the bathroom at the rear of the property. However, installation of the Wallas unit seems to have cured the damp in the bathroom and has greatly improved conditions at the front of the building with initial feedback from attendants and service personnel being very positive with reports that air in the dwellings when visited after being closed up for over a month was '*fresh and sweet*'. Unfortunately, although the Wallas unit is specified for operation in a marine environment they are not designed for continuous use and its fan failed after about two years but during that time it proved to be highly effective in terms of improved building conditioning.

Figure 12: Bull Rock Lighthouse

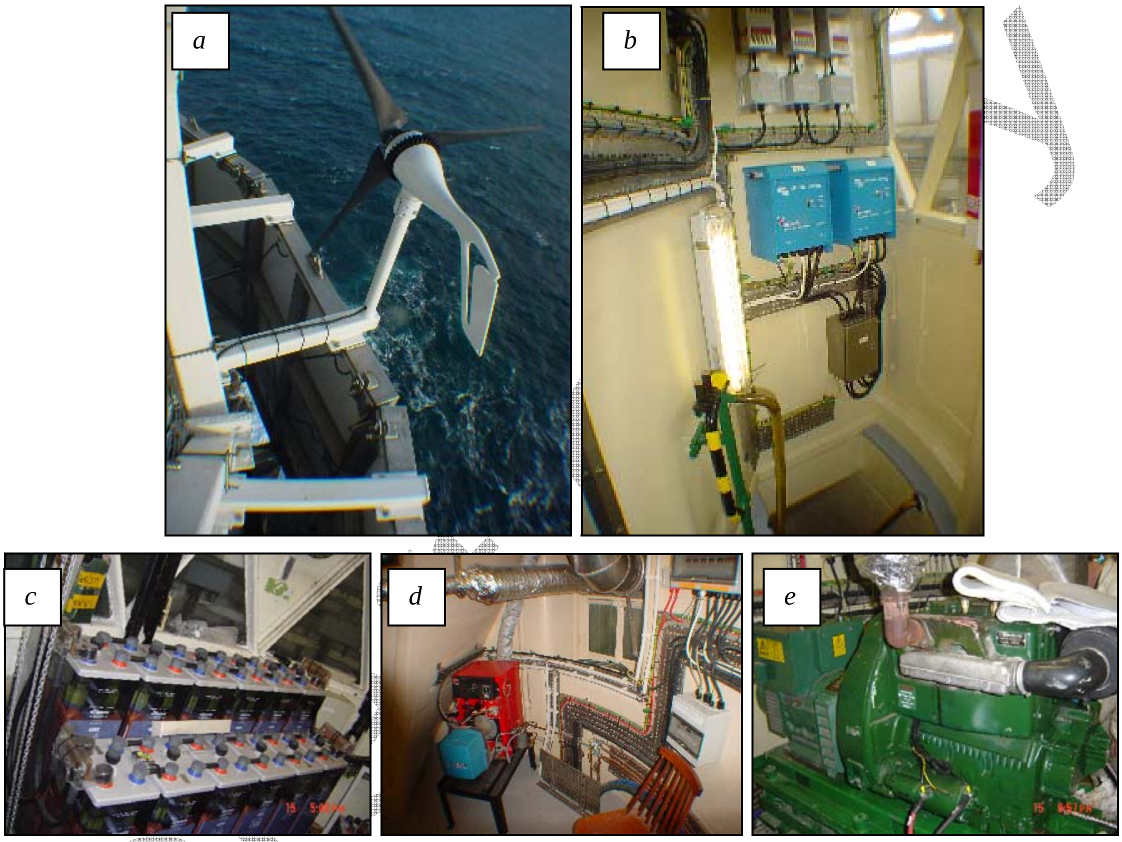
Following the success of the Bull Rock trial, two Wallas units were installed at Skelligs (CIL sites 29 in Figure 8) with good results. The two units were required at this station because of the building size.

2.6.2 Rock Towers

Longships Lighthouse (TH) (See Report Cover) – Longships is a rock tower lighthouse constructed in 1875, automated in 1988 and modernised in 2006 with a change over from 24/7 diesel power generation to the introduction of a hybrid system comprising solar panels, wind turbines, oil-fired boiler, batteries, invertors for domestic heating and day facility and a re-conditioned diesel generator. Longships lighthouse is located approximately 3km off Land's End in Cornwall and is also described as being in the 'Very Severe' exposure category in terms of wind speeds and driven rain (TH site 33 in Figure 8). In planning the modernisation of Longships a concerted attempt was made to include sufficient power generation capacity for building conditioning. This necessitated the installation of the hybrid generation system described above and shown in Figures 13 & 14a–e with controller systems that can be operated remotely to adjust the conditioning regime as necessary. So, for example, the heating regime can be remotely activated to counteract increases in relative humidity.

Figure 13: Longships lighthouse with solar panels to provide power to the navigational aid, main, standby and facilities battery bank. Brackets fitted for four 400W wind generators to supplement the charging regimes

Since the system was commissioned in 2006, the building has been exposed to a regulated heating regime in the summer of one hour each day rising to two hours and four hours in the winter. This regime has proved sufficient to maintain relative humidity levels below 70%, decrease the incidence of condensation and associated problems of mould growth and corrosion. The change from 24/7 diesel generation to the hybrid system has also produced environmental benefits through the reduction in CO_2 emission by greater reliance on renewable energy sources and through the reduced number of service visits and associated ship and helicopter operations.



Figures 14: Images showing components of the hybrid energy generation system at Longships lighthouse; (a) Airmarine (400W) wind turbines, (b) AC invertors, (c) One of the three battery banks, (d) 'KABOLA' Oil fired boiler, (e) Reconditioned 'Lister TS3' 10kW diesel generator set

Hanois Lighthouse (TH) – Hanois was established in 1862 and converted to fully automated status in 1996. The tower is located on the Les Hanois Rocks approximately 1km off Pleinmont Point, Guernsey (TH site 67 in Figure 8) and is classified as being exposed to 'Very Severe' conditions in terms of wind and driven rain (Figure 15a). A solar array provides power for the Navigation Aids with a diesel generator cycled for battery charging or when personnel are on station with the generator remotely activated if requested, several days prior to the arrival of personnel.

Because of the necessity of keeping the tower as water-tight as possible with regard to both weather and 'green water', ventilation within Hanois is limited to air infiltration through a small open scupper in the lower bronze entrance doors and windows at higher level. This lack of ventilation combined with intermittent and limited heat generation has resulted in widespread mould growth especially in the lower levels of the tower and deterioration of painted surfaces (Figure 15b). In the absence of major capital works such as those at Longships, the action planned for Hanois comprises a much simpler and economic approach to improving building condition comprising the following:

- Installation of a ‘Premaberg’ ventilator within the lower bronze window but fitted in such a way as to be reversible within the context of the historic integrity of the window frame.
- Opening of a disused vent in the gallery with fitting of a stainless steel revolving cowl to increase the draw of air up through the tower.
- Removal of all paint film on the walls of the staircase.
- Possible introduction of solar fans with the panel positioned in the staircase window and the fan fitted as required within the stairwell.
- With the exception of the engine room, all doors within the tower are to be kept open when personnel are not on station.

Figures 15: (a) Exterior of Hanois lighthouse and, (b) interior of the tower showing deterioration of painted surfaces

2.7 SOME BASIC DO'S AND DON'TS OF BUILDING CONDITIONING

Building conditioning of lighthouses and associated structures may require compromises to be made between the best conditions that can be established and the power available to achieve these. However, there are some basic DO'S and DON'TS that should be followed in the conditioning of any building:

DO:

- Ensure that the external fabric of the building is sound with no structural weaknesses through which moisture can penetrate.
- Address any problem of rising damp.
- Ensure that all glazing is watertight.
- Regularly check that all wooden window frames are sound and free from rot.
- Ensure that all external finishes are sound.
- Check for leaks around the gallery as many cast-iron murettes because of their age are showing signs of deterioration and, in some cases, are starting to leak.
- Check that where buildings have concrete roofs the differential expansion cracks between the roof soffits and the walls are properly sealed.
- Ensure adequate ventilation exists for the method being used to provide conditioning.
- Provide notices informing visiting personnel which internal connecting doors are to be left open for ventilation purposes when leaving the station.
- Expect the walls of naturally ventilated stations to occasionally show signs of condensation – protect electronic items with suitable enclosures.
- Consider the type and quality of soft furnishings left on station in the context of the condition status of the buildings.

DON'T:

- Import excess moisture in wet clothing, as steam from cooking, kettles etc.
- Cover up sources of damp – identify and rectify the problem as quickly as possible.
- Expect a station to remain in pristine condition unless 24/7 heating is provided.

3. SECTION THREE: MONITORING

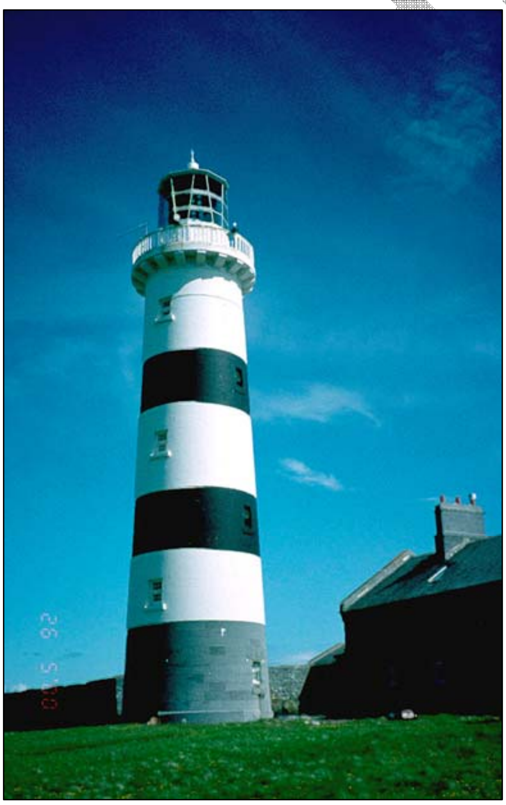
3.1 WHY MONITOR?

Monitoring conditions within lighthouses and associated buildings is an important part of any condition management strategy. With regard to building condition, the most important parameters are air temperature and relative humidity – if these are adequately controlled then internal building condition should be relatively good although it is important to remember that unoccupied buildings will always be at risk of deterioration especially when located in exposed coastal areas.

Monitoring environmental parameters such as air temperature and relative humidity is extremely useful because it allows:

- Assessment of overall condition status prior to development of conditioning strategies through characterisation of the prevailing temperature and humidity profiles within a structure
- Subsequent evaluation of the success (or failure) of implemented conditioning strategies
- Long-term monitoring of sensitive structures that have a history of conditioning problems

Ideally, monitoring should be carried out on a long-term basis over at least one year (preferably longer) to allow for seasonal variations in environmental parameters and to enable the severity of conditions to be realistically assessed. Different parts of the structure should be monitored as the design of a building can have a significant effect on its internal environmental conditions.



For example, monitoring identified the existence of a clearly defined stratification of humidity within Eeragh lighthouse (CIL site 41 in Figure 8) reflecting a 'stack' effect whereby warmer and drier air rises to the upper floors of the tower leaving cooler and more humid air in the lower levels (Figures 16a & 16b).

The design of this tower has created a natural stratification of humidity levels with approximately 10% difference between values in the upper and lower floors. Such differences in micro-environmental conditions will need to be taken into consideration during planning for improvements to the status of building condition.

Figure 16a: Eeragh lighthouse, which comprises a total of seven floor levels excluding the lantern/optic

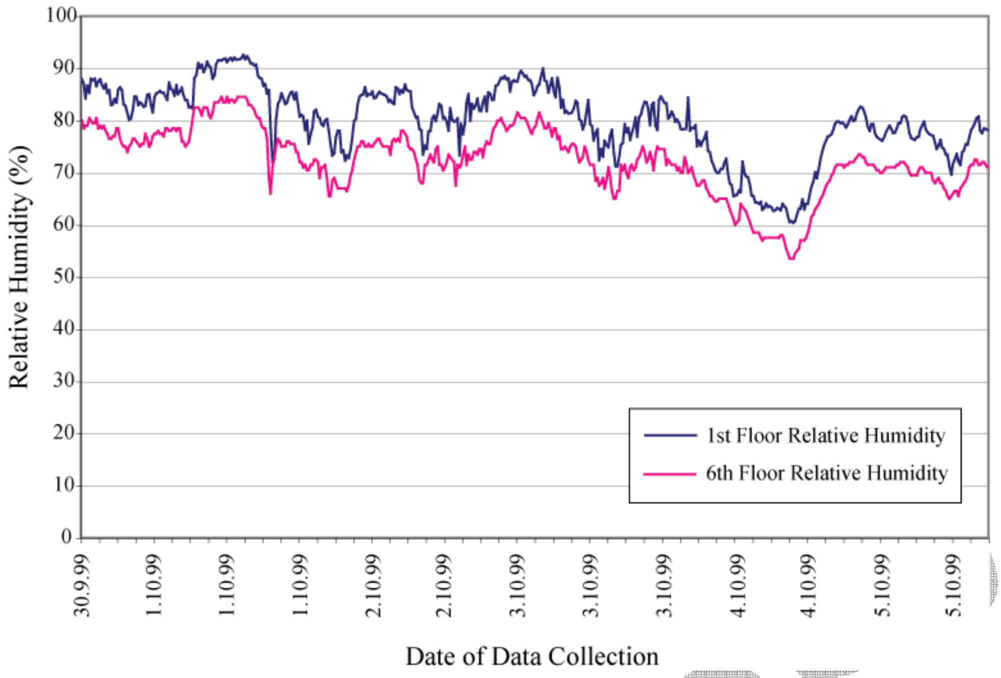


Figure 16b: Variation in relative humidity values between the 1st and 6th floor levels within Eeragh lighthouse (CIL site 41 in Figure 8)

3.2 METHODS OF MONITORING

This section will include an outline of the different methods of monitoring the internal condition of stations including remote telemetry and *in situ* data recorders (e.g. HOBO system).

In order to understand the temperature and humidity conditions inside lighthouses, TH deployed HOBO data-loggers recording values every hour (Figure 17a). At North Foreland, for example, these were placed externally and internally in the mezzanine, within the tower itself and in the service room. Data extracted from these loggers gave information about seasonal and daily trends of air temperature, relative humidity and dew point (Figure 17b). The HOBO units are relatively cheap, unobtrusive and generally quite robust often providing many years of continuous service.

Figure 17a: HOBO data-logger in situ at North Foreland Lighthouse

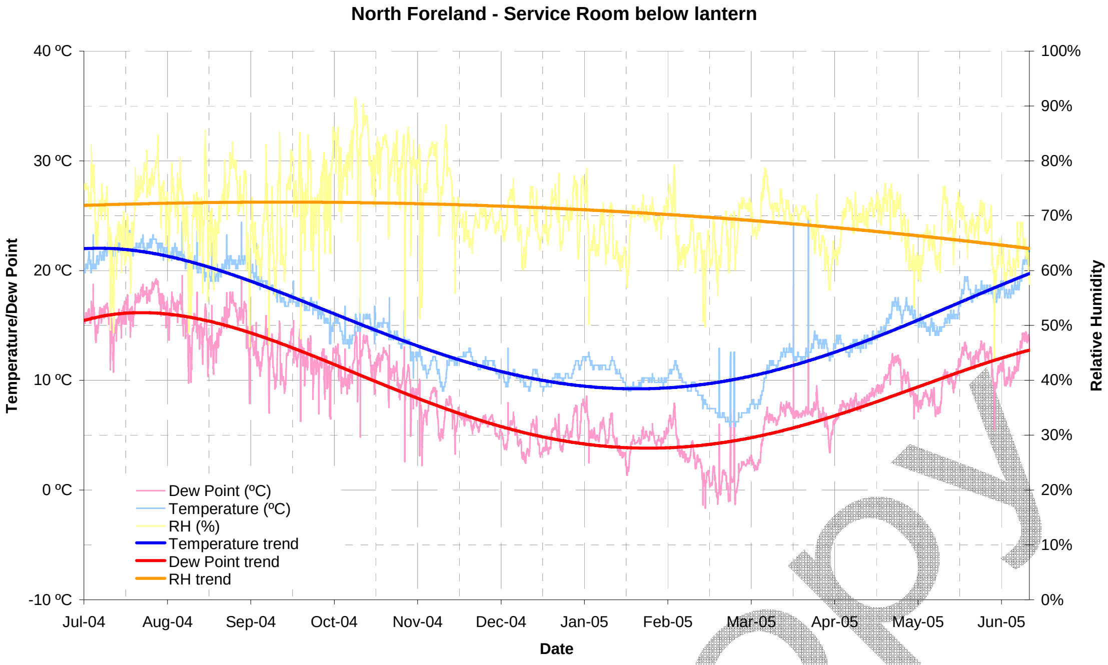


Figure 17b: This graph shows the seasonal trends in temperature, relative humidity and dew point data recorded by a HOBO unit in the service room in North Foreland during 2005 – 2006.

3.3 CASE STUDY: LONGSHIPS LIGHTHOUSE

As part of the solarisation project for Longships Lighthouse, a new system of building conditioning needed to be installed to ensure the continued good condition of the interior of the tower following the removal of the 24/7 heating afforded by the continuous running generator set. The system employed was a diesel-fired boiler used to provide heating to radiators suitably distributed within the tower with each radiator fitted with a thermostatic valve to allow localised temperature control. Water was circulated using a low power 24v pump. The system was appropriately sized to provide comfortable living conditions when personnel are on station.

The principle behind the operation of this system is to run the boiler for a given period of time each night, thereby endeavouring to maintain warmth within the structure. When personnel visit the station for maintenance purposes, the system reverts to continuous running with the temperature in each area set by the thermostatic radiator valves. When the tower is unoccupied, the duration that the boiler is operational for each night can be adjusted to meet the thermodynamic properties of the building and to offset the effects of seasonal changes in temperature.

The primary aim of the system was to minimise any adverse effects to the internal condition of the structure resulting from the cessation of continuous (24/7) heating and any associated rise in relative humidity. In addition, the system aimed to keep the building fabric and soft furnishings in satisfactory order and to provide a warm and comfortable living area for personnel visiting the station. With a reduction in generator running time a decrease in fossil fuel use was another positive outcome of the new building conditioning system.

A simple monitoring system was installed in the service room just below the lantern of this rock tower lighthouse. This monitoring system was integrated into the lighthouse telemetry system, which records both temperature and humidity. The periodicity of the sampling of this data can be adjusted within the telemetry system and this feedback of performance allows changes to the run time of the boiler to be proposed and implanted to achieve the goals of the system for the minimum use of fossil fuels.

Figure 18 is an extract from the telemetry monitoring system covering a period of about one month from October to November 2008. It can be seen that each night the boiler raises the temperature of the service room with an associated reduction in the relative humidity thus successfully maintaining general humidity levels within a desired range that is conducive to the maintenance of good building conditioning.

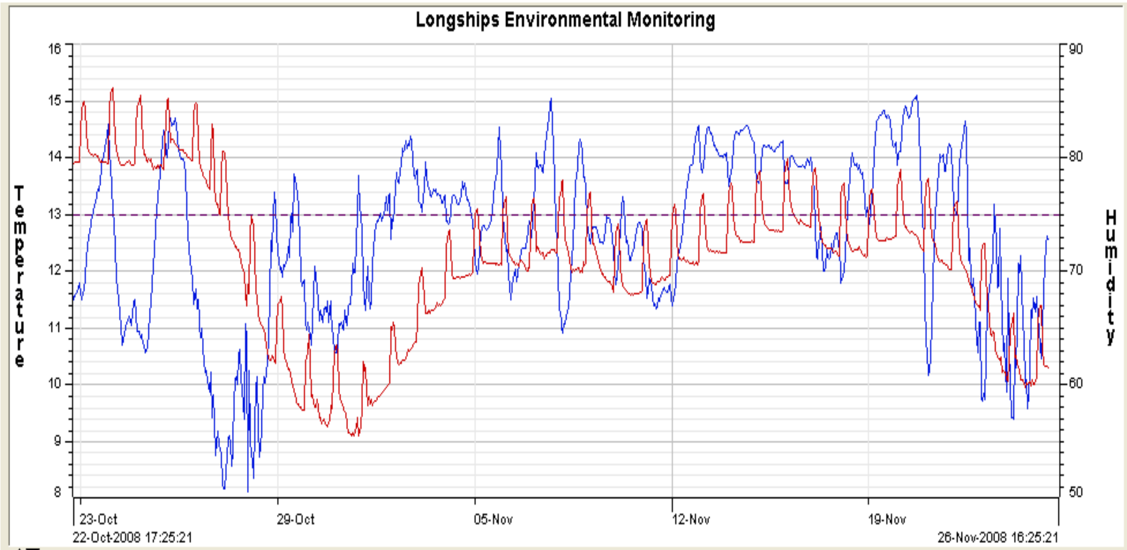


Figure 18: Snapshot of air temperature (red line) and relative humidity (blue line) data from the Service Room in Longships Lighthouse showing the regular spikes in temperature resulting from the night-time activation of the heating system and the less regular fluctuations in relative humidity conditions within the tower that reflect both the internal heating regime and the influence of external meteorological conditions.

SECTION FOUR: RECOMMENDATIONS

4.1 CONDITION CHECKLISTS

There are numerous issues affecting the external and internal condition of a building but nearly all can be prevented from assuming great significance by regular monitoring and prompt and appropriate intervention. Completion of a rapid survey checklist during each site visit is a proactive approach to the maintenance of building condition, which allows early identification of potential problems that can either be addressed immediately or incorporated into future service visits.

Examples of such checklists used by Trinity House for land-based lighthouses and rock towers are shown in Tables 16a & 16b. The differences in size of checklist and frequency of completion reflects the fact that compared to Flamborough Head, Eddystone Lighthouse (Table 16a) is a rock tower station that is visited less regularly because of its off-shore status and because it comprises only a tower with no ancillary buildings.

Table 16a: Condition checklist for a rock tower station (Eddystone Lighthouse: TH site 25 in Figure 8)

Eddystone Lighthouse Attendants Check Sheet			
	Activity	**Jan**	**to**
7.00	**SECTION 7 --- CONDITION OF PREMISES**		
7.01	Tower external condition inspection. In particular condition and fit of doors, general paintwork, windows, steps, fixed ladders, platforms, staircases, handrails and woodwork.		✓
7.02	Tower internal condition inspection. In particular damp, leaking windows, paintwork, floors, internal doors, water leaks, function of toilets and sinks.		✓
7.06	Access condition inspection. Boat landings, helipad, roads, paths.		✓
7.08	Station domestic equipment inspection, fittings, fixtures and furniture, function of toilets and sinks.		✓

Table 16b: Condition checklist for a land-based lighthouse (Flamborough Head: TH site 8 in Figure 8)

Flamborough Head Lighthouse Attendants Check Sheet				
	Activity	**Jan**	**Feb**	**Mar**
	SECTION 7 --- CONDITION OF PREMISES			
7.01	Tower external condition inspection. In particular condition and fit of doors, general paintwork, windows, steps, fixed ladders, platforms, staircases, handrails and woodwork.	✓	✓	✓
7.02	Tower internal condition inspection. In particular damp, leaking windows, paintwork, floors, internal doors, water leaks, function of toilets and sinks.	✓	✓	✓
7.03	Accommodation / outbuildings / cottages external condition inspection. External woodwork, roof, rain goods, windows and paintwork.	✓	✓	✓
7.04	Accommodation / outbuildings / cottages internal inspection. Check for water ingress, damp, paintwork, floors, internal doors, function of toilets (flush) and sinks.	✓	✓	✓
7.05	Grounds condition inspection. Gates, fences, boundary walls, signage, excessive weeds, drains and gullies, septic tanks.	✓	✓	✓
7.06	Access condition inspection. Boat landings, helipad, roads, paths.	✓	✓	✓
7.07	Cliff/coastal erosion. Measure/monitor station specific details.	✓	✓	✓
7.08	Station domestic equipment inspection, fittings, fixtures and furniture, function of toilets and sinks.	✓	✓	✓

4.2 FREQUENTLY ENCOUNTERED CONDITIONING ISSUES

Table 17 provides information regarding building conditioning issues and recommendations for their treatment. This list is not exhaustive but gives a flavour of the most frequently encountered problems associated with unoccupied structures exposed to the extreme conditions encountered in coastal environments.

Table 17: Frequently encountered building conditioning issues and approaches to treatment

Description of Issue	Photo	Recommended Intervention
Roofs & Rain Water Goods		
Missing and damaged slates and guttering allow rain to penetrate the fabric of the building		Regular checking of rainwater goods and roofs as part of each site visit with prompt repair and/or replacement being essential.
Inadequate or poorly fitted roof lagging		Poor roof lagging reduces heat retention within the building and can have an adverse impact on building condition. It is important to check that loft insulation is properly fitted and is of adequate depth (270mm is currently considered to be the optimum depth) while still allowing ventilation to eaves.
Cracking of asphalt roof membrane which, if neglected will result in moisture penetration		Regular monitoring of the condition of asphalt roofs and reporting of any potentially related internal evidence of damp. Repair asphalt (qualified contractor required) or overcoat with reinforced liquid membrane.
Blocked drains and gallery flooding		Regular monitoring of gallery drains is necessary to avoid blockage by debris and dead birds especially when the gallery is surrounded by a solid parapet. Existing drainage holes may need to be enlarged and/or new ones added to ensure the rapid and efficient removal of water.
Blocked gully in asphalt roof which can cause flooding of the roof and moisture ingress through flashings		Regular monitoring of gallery drains and gullies is essential in order to maintain rapid removal of water and prevent overspill flooding into elements of the building.

Table 17 continued

Description of Issue	Photo	Recommended Intervention
Flooding of a flat roof		Blocked drains have resulted in this flooded roof. A situation like this requires urgent attention because of the risk of significant moisture ingress into the fabric of the building.
Corrosion & Metalwork		
Internal of lantern surface showing extensive corrosion		Internal corrosion is associated with external moisture penetration and/or the presence of surface condensation within the lantern. Identify and seal external moisture access points and control condensation through improved ventilation.
Moisture trapped between the two ‘skins’ of the ventilator has lead to corrosion and associated staining of external surfaces		Check for blockage of the ventilator, as inadequate airflow may be the reason for moisture retention and associated corrosion-related staining. This may require removal of the ventilator to facilitate a full repair or replacement.
Rusting of beam ends due to moisture ingress and/or surface condensation		Identify and seal any external defect that has allowed moisture to penetrate walls. Remove paint from adjacent wall and rusting metalwork to facilitate drying. This may also necessitate the fitting of a low voltage anode system.
Rusting soffit plates below the lantern room due to water ingress from defective lantern glazing and/or moisture within the wall as the plate is built into the render on its back edge		Repair defective lantern glazing. If the soffit plate is badly affected it may be removed if the building does not have listed status. However, if it is listed then the soffit plate may need to be replaced.
Corrosion of fixings behind a new stainless steel tray with associated staining of adjacent painted surface		Where possible corrosion resistant stainless steel fixings should be used when attaching components to solid masonry walls especially external walls that may contain moisture. This should prevent corrosion and the problems associated with surface staining. When such corrosion staining does occur, all ferrous fixings such as old electrical fixings, nails, screws and exhaust manifolds should be removed and replaced, where necessary with corrosion-resistant equivalents.

Table 17 continued

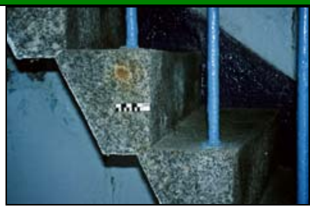
Description of Issue	Photo	Recommended Intervention
Corrosion-related staining of granite stonework		Staining of stonework associated with corrosion of embedded ironwork is the first sign of deterioration of ironwork which will eventually result in fracturing of adjacent stonework due to corrosion-related expansion of ironwork.
Moisture Ingress & Deterioration of Internal Surfaces		
Flaking, peeling and loss of paint associated with moisture in masonry materials and excess surface condensation		If the building is not used for accommodation paint removal should be considered. This will allow affected masonry to 'breathe' and facilitate drying. Checks of the building exterior should be made for any defects that might facilitate moisture penetration. The situation may also be improved by increasing ventilation. If the building is required for accommodation then thought must be given to introducing or increasing the duration and extent of heating along with improved ventilation.
Salt efflorescence on internal painted surfaces with associated degradation of painted finish		Check external wall surface for evidence of defects that may have aided moisture ingress and repair if present. Remove paint (and plaster if damaged) from internal walls or allow to fall off as this will allow masonry material to 'breathe' and thus facilitate moisture release.
Rotten lath and plaster caused by moisture penetration, a lack of ventilation and bridging of delaminated material		Breakdown of lath and plaster will require replacement with identification and repair of any moisture access point. Walls should be allowed to dry-out before lath and plaster is replaced. Ventilation may need to be improved in order to reduce surface condensation.
Excessive damp in basement room		Removal of decorative coatings and render in basement room which has improved condition by allowing masonry materials to 'breathe' and dry-out
Damage to internal painted surfaces resulting from moisture penetration due to missing slates and guttering		Regular checking of rainwater goods and roofs as part of each site visit should pre-empt significant damage. Following repair interior surface materials will need time to dry-out and should therefore be left unpainted for some time following repair to facilitate this.

Table 17 continued

Description of Issue	Photo	Recommended Intervention
Patterned breakdown of painted surfaces associated with moisture		Moisture and salts preferentially drawn in through block joints and mortar resulting in emulsification (saponification) of alkyd (oil-based) paint. Check external wall surface for evidence of defects that may have aided moisture ingress and repair if present (e.g. defective external paint and/or degraded mortar). If the problem is widespread, paint should be removed to allow masonry to 'breathe' and release moisture.
Delamination of painted lining paper from a ceiling primarily caused by moisture ingress and poor internal ventilation		Remove lining paper to allow the ceiling to dry-out. Check roof for any evidence of defect and route for moisture ingress. Excessive surface condensation will need to be addressed by improving ventilation and/or increased provision of heating.
Breakdown of rendered and painted internal surface associated with salt crystallisation and growth through underlying masonry		In severe cases render/plaster should be removed to allow underlying masonry to 'breathe' and aid drying. External wall surfaces should be checked for defects that may have facilitated moisture penetration.
Blistering and loss of internal surface paint as a result of moisture and salt		Check external wall surface for evidence of defects that may have aided moisture ingress and repair if present (e.g. defective external paint, structural cracking or degraded mortar). If the problem is widespread, paint should be removed to allow masonry to 'breathe' and release moisture. When removing historic paint protective measures should be taken as some of the older paint may be lead-based.
Salt efflorescence on a granite floor		Patterns of salt efflorescence on the granite floor reflect airflow patterns created by the freestanding dehumidifier which forces salt crystallisation from stone that has previously suffered the effects of salt-rich moisture penetration into the tower. Removal of the dehumidifier reduced the amount of salt efflorescence and hence crystallisation related breakdown of the stone surface.

Table 17 continued

Description of Issue	Photo	Recommended Intervention
Severe discolouration of internal surface by mould and corrosion related staining associated with moisture penetration		Address issue of moisture ingress as a matter of urgency. Remove paint layers and any surface render/plaster (if present) to allow masonry to dry-out. Caution should be taken during removal of paint as historic layers may contain lead. These actions should be associated with efforts to improve ventilation. The process of drying may take months or even years in severe cases and, therefore, no attempt should be made to re-paint surfaces until their condition has stabilised.
Mould growth on soft furnishing fabric which, as well as being unsightly, results in breakdown of material		If possible, affected fabric should be laundered to kill mould and subsequently protected from exposure to damp conditions when not in use. If this is not possible, damp conditions will need to be addressed by improved ventilation and provision of additional heat.
Glazing		
Water ingress through defective lantern glazing		Regular checks of lantern glazing and prompt repair of damaged panes and/or defective mountings.
Breakdown of painted surfaces and underlying masonry materials around windows, doors etc.		Water and salt ingress around window joinery resulting in destabilisation of painted surface associated with salt crystallisation. Identify and repair site or area of moisture ingress. Remove paint and loose material from affected area to facilitate drying. The area may need to be left unpainted for some time to allow the affected surface to stabilise.
Internal window condensation		Internal window condensation can be removed by drains thereby preventing the accumulation of moisture which may lead to corrosion of any metal fittings and/or rot of woodwork.

Table 17 continued

Description of Issue	Photo	Recommended Intervention
Salt-rich moisture penetration around window with breakdown of granite stonework and loss of painted surface		The problem was exacerbated in this instance by the presence of a disused duct cut into the external granite by the window casing. This allowed moisture penetration and saturation of the internal granite block. The duct should be sealed using a mix of granite dust and hydraulic lime mortar with excess salt and loose surface granite debris brushed off and removed. In extreme cases it may be necessary to 'dress back' and reface the affected portion of internal stonework in order to prevent further deterioration.
Woodwork / Joinery		
Rotting of window joinery due to breakdown of protective paint cover		Regular application of paint will prevent initiation of wood rot and eventual penetration of moisture.
Weathered external paintwork on joinery elements		Opening of joints in woodwork, if neglected, will eventually allow moisture penetration and possible initiation of rot.
External Surfaces		
Cracked and degraded render		In some cases re-rendering may be required to maintain building condition when 'old' render cannot prevent moisture ingress because it has become so cracked and degraded.

Table 17 continued

Description of Issue	Photo	Recommended Intervention
Cracking of external tower surface		Render repairs should be carried out as a matter of urgency to prevent moisture ingress and initiation of internal moisture related problems or exacerbation of pre-existing ones.
Peeling external paint film resulting from defective adhesion with underlying surface		Peeling paint is indicative of problems beneath the painted film surface. This may be due to inadequate preparation with the underlying surface being too smooth or greasy for the paint to bind to. Remove peeling paint layer, prepare underlying surface and reapply surface coat.
Breakdown of thick coating of lime wash on a boundary wall		Thick lime wash and lime renders protect walls built of rubble stone or porous brick and walls in exposed locations facing driving winds. The layer of lime acts like a sponge, absorbing rainfall and allowing it to evaporate rather than soak into the wall. It may be possible to repair and consolidate cracked render and thick lime wash with patch repairs. On the wall shown, patch repairs of the wall cap should provide sufficient protection.
Miscellaneous		
Insufficient energy from renewable sources for building conditioning		Installation of oil-fired boiler (Kabola) for wet central heating system.

Table 17 continued

Description of Issue	Photo	Recommended Intervention
Restricted passive ventilation associated with closed ventilation slat in lantern		Remove paint and restore to operational condition. These ventilation slats should be used to facilitate the natural draw of air up through the tower which will, in turn, help to reduce condensation and improve building condition.
Ground instability can pose a significant threat to the structural integrity of a building		Rotational slips and slumps combined with ongoing coastal erosion and removal of soft sediments is undermining the stability of the lighthouse complex at St. Catherine's (TH site 18 in Figure 8). This requires monitoring of the tilt of the tower and tension cracking in external walls and road surfaces. Costly engineering works would be required to stabilise the site in the medium-term.
Coastal erosion and sea-level rise		Coastal erosion, sea-level rise and increased severity of storm events pose a threat to many lighthouses on both soft and hard rock coasts. At Orfordness (TH site 12 in Figure 8) erosion of the shingle beach has brought the storm surge limit close to the tower. Eventually the tower will be undermined. The only realistic options are to either physically relocate the tower or to abandon the site and erect an alternative Navigational Aid further inland.

APPENDICES

APPENDIX 1:
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MAP SHOWING LIGHTHOUSE EXPOSURE CATEGORIES

APPENDIX 1: GLOSSARY OF TERMS

AC/DC: Alternating or Direct electrical current. AC is an electric current produced by induction in a generator whose direction reverses cyclically, as opposed to DC electricity where the direction remains constant

CIL: Commissioners of Irish Lights

Condensate: water formed by the process of condensation

Condensation: the process whereby water condenses out of air containing water vapour when its temperature drops to or below dewpoint

Day Mark: during the hours of daylight lighthouse buildings themselves act as aids to navigation. Consequently, they are painted white with low-lying stations that back onto cliffs often striped with red or black to make them more conspicuous. Most rock towers are not painted but the lights are operational for 24 hours to maintain their visibility

Deliquescence: this is the process by which a substance absorbs moisture from the atmosphere until it dissolves in the absorbed water and forms a solution. All soluble salts will deliquesce if the air is sufficiently humid. A substance that absorbs moisture from the air but not necessarily to the point of dissolution is called hygroscopic

Dewpoint: the temperature at which air becomes saturated with water vapour (100% relative humidity)

Driving Rain: the meteorologist's term for heavy rain combined with the penetrating force of a strong wind

Efflorescence: visible manifestation of salt in crystalline form on masonry surfaces

GLA: General Lighthouse Authority

Green Water: a term used to describe seawater

Hygroscopic Material: material that has the ability to attract water molecules from the surrounding environment through either absorption or adsorption

Interstitial Condensation: condensation that occurs within or between layers of the building envelope

Listed Buildings: the listing of a building marks it out as having special historic significance and affording it protection under planning legislation

Moisture Content: proportion of water contained within a material (expressed as mass/mass, in percentage terms)

Moisture Content of Air: the ratio of the mass of water vapour present in air to the unit mass of dry air

NLB: Northern Lighthouse Board

Positive Pressure Airflow: maintenance of a flow of air within a building through the use of ventilation pumps

Psychrometric Chart: the psychrometric chart is a graph of the physical properties of moist air at a constant pressure (often equated to an elevation relative to sea level), which graphically expresses how various properties such as dry and wet bulb temperatures, dewpoint and relative humidity relate to each other

Relative Humidity (RH): the ratio of the partial pressure of water vapour in the mixture to the saturated vapour pressure of water at a prescribed temperature

Reverse Condensation: interstitial condensation formed by water vapour traveling from outside to inside (i.e. reverse of normal condensation)

Saponification: this is the formation of water-soluble soaps and is most often associated with the chemical attack of an oil-based or alkyd paint by a highly alkaline masonry substrate or exposure to damp alkaline conditions such as those experienced in a salt-rich coastal environment

Saturation Vapour Pressure: water vapour pressure in air at dewpoint temperature

Schedule 1 Painting: this describes the extent of external and internal painting of stations with Schedule 1 indicating external painting of the lighthouse, cottages, associated buildings and boundary walls while Schedule 2 painting describes the 'touching-up' of painted surfaces

Scupper: with regard to lighthouses this is a drain in the sill of the outer storm shutters and lower entrance doors of rock tower lighthouses that allows water to drain out

Spell: a period or sequence of periods of wind-driven rain on a vertical surface

TH: Trinity House

Thermal Bridge (Cold Bridge): part of a structure of lower thermal resistance which bridges adjacent parts of high thermal resistance and which may result in localized cold surfaces on which condensation and/or pattern staining may occur

Thermal Inertia: this is a bulk material property related to thermal conductivity and volumetric heat capacity and is a measure of the thermal mass and the velocity of the thermal wave which controls the surface temperature of a material (i.e. the ease with which a material takes in or gives off heat)

Thermal Mass: a measure of the ability of a substance to absorb and store heat

Vapour Pressure: that part of atmospheric pressure due to water vapour present in the air

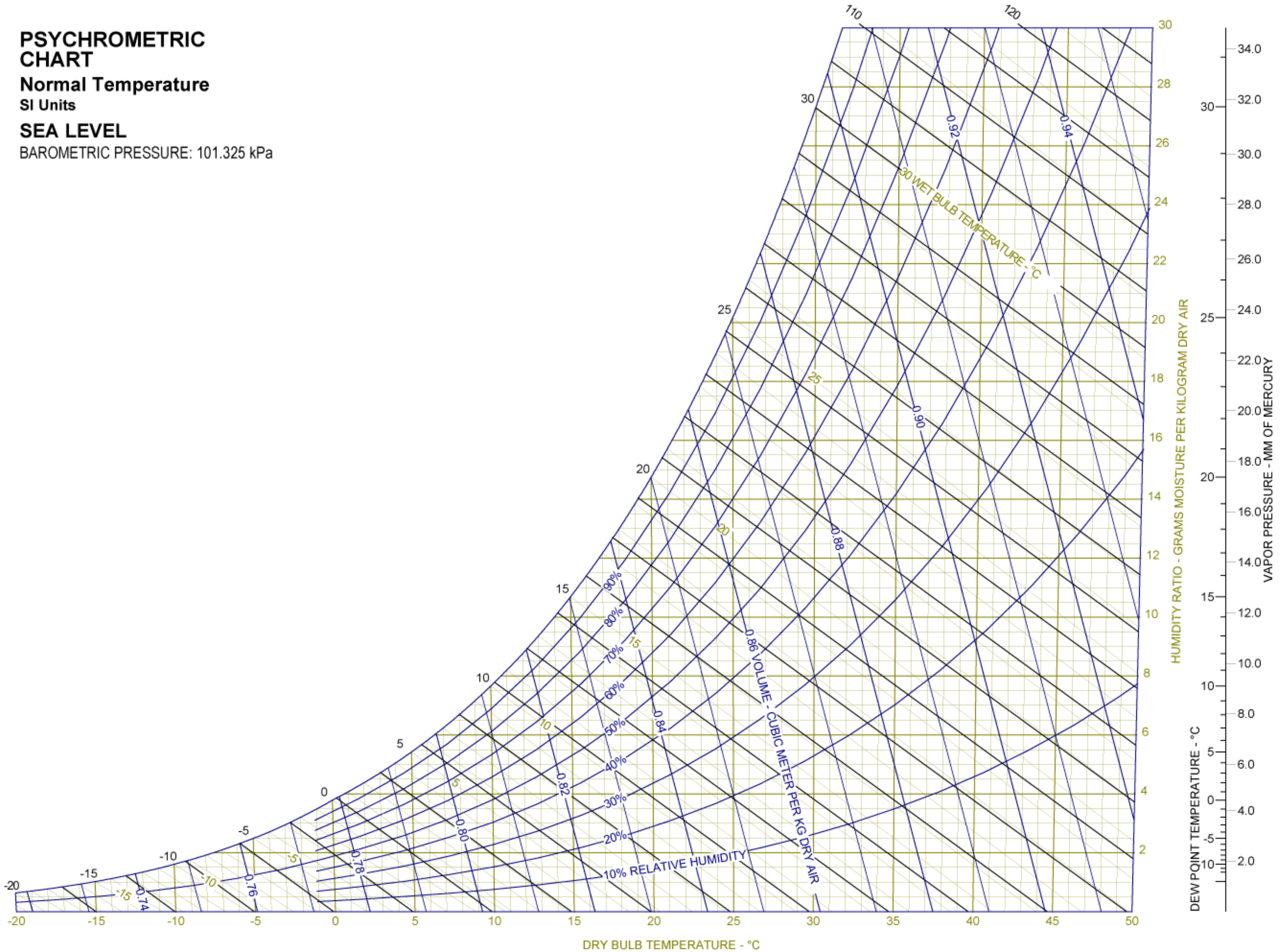
Ventilation Heat Exchange: used to describe a ventilation system that recovers heat energy from air before it is expelled from a building which is then used to warm incoming fresh or replacement air

Ventilation Rate: the rate at which air within a building is replaced by fresh air. This may be expressed as the number of times the volume of air within a space is changed in one hour (air changes per hour: ac/h) or as rate of air change expressed in cubic metres per hour (m^3/h)

Water Vapour: water in its invisible gaseous phase

APPENDIX 2:

BLANK PSYCHROMETRIC CHART


PSYCHROMETRIC CHART
Normal Temperature
SI Units
SEA LEVEL
BAROMETRIC PRESSURE: 101.325 kPa
30 WET BULB TEMPERATURE - °C
VOLUME - CUBIC METER PER KG DRY AIR
10% RELATIVE HUMIDITY
DRY BULB TEMPERATURE - °C
HUMIDITY RATIO - GRAMS MOISTURE PER KILOGRAM DRY AIR
VAPOR PRESSURE - MM OF MERCURY
DEW POINT TEMPERATURE - °C

APPENDIX 3:

DETERIORATION OF STONEWORK IN LIGHTHOUSES: AN OVERVIEW

DETERIORATION OF STONEWORK IN LIGHTHOUSES: AN OVERVIEW

When considering the factors contributing to deterioration of stonework in lighthouses it is important to distinguish between spatial and temporal patterns of decay and to recognise the complex nature of stone response to environmental conditions. At the outset it is important to stress that stone affected by the presence and action of salts cannot be returned to its original 'quarry fresh' condition or the condition it was in at the time of construction. Remedial intervention is therefore aimed at controlling and slowing rates of deterioration with avoidance of well-intentioned but overly aggressive or inappropriate treatments that can accelerate rates of pre-existing deterioration or trigger the decay sequence by destabilising previous stable stonework.

Spatial variability of stone deterioration

Decay is not ubiquitous – it does not affect all stonework equally within the tower and, therefore, planning remedial intervention can be problematic. At a general level the extent and severity of decay normally decreases with increasing height in a tower although this pattern can be easily over-written by site-specific factors related to such events as external moisture penetration at some time in the past which continues to drive present-day deterioration processes. Consequently, a detailed understanding of the history of the tower is an essential component in the design of successful future management strategies.

Spatial variability is also evident at much smaller scales with regard to the condition of individual sandstone units and is normally related to the impact of factors such as:

- Location of extractor fans that facilitate the development of salt efflorescence through concentration of airflow at the stone/air interface.
- Presence of dehumidifiers that can encourage surface salt crystallisation with associated deterioration of stonework.
- Corrosion and volumetric expansion of embedded ironwork.

By analysing the spatial distribution of stone alteration, identifying potential contaminant inputs and associated variations in micro-environmental conditions, it should be possible to identify the factors controlling contemporary decay and thus more accurately inform decision making with regard to immediate remedial action and development of future management strategies.

Temporal variability of stone deterioration

Change is an inherent characteristic of stone and is a product of the conditions of exposure and the natural adjustment of stone overtime to these conditions. It is important to remember that stone behaves differently from other manmade masonry material primarily because it is typically formed under conditions of great heat and/or pressure many hundreds or thousands of metres below the Earth's surface.

When it is exposed to surface conditions **ALL** stone starts to deteriorate through the process of weathering – a process that reflects the readjustment of constituent minerals within the stone to surface conditions where temperature and pressure regimes are much lower. Put simply, the process of stone weathering involves mineral alteration to forms that are more stable with an associated destruction and loss of less stable material. The rate at which this destruction and loss of material occurs reflects the properties of the stone itself and the nature of the environment it is exposed to.

Factors contributing to stone deterioration through salt weathering

Three factors can act to keep the stone decay process going:

- **Gravity-related debris release**. Weathering of stone is best maintained by the regular removal of weakened and friable material. On ceilings, this occurs naturally due to the effects of gravity and the release of debris onto the floor below leaving a ‘new’ surface for salts to act upon. In addition gravity facilitates the downward movement of moisture and salts within stone. Over time the actual surface of the stone will gradually retreat as original surface layers are lost. However, this is a very gradual process but helps to explain why weathering related damage to ceilings tends to be more severe than that exhibited by stone floors.

Table 1. Examples of tensile strengths of rock in comparison to typical pressures exerted by some common salts during salt crystallisation and the volume expansion associated with salt hydration.

Typical ranges of tensile strengths of various rocks (MPa)	
Extremely high strength rocks	>10
Very high strength rocks	3–10
High strength rocks	1–3
Medium strength rocks	0.3–1
Low strength rocks	0.1–0.3
Very low strength rocks	0.03–0.1
Extra low strength rocks	<0.03

Typical pressures produced by salt processes (MPa)	
Crystallisation pressures of gypsum	28.2–19.0
Crystallisation pressures of sodium chloride	5.54–373.7
Crystallisation pressures of sodium sulphate	29.2–196.5
Hydration pressures of gypsum	Up to 254
Hydration pressures of magnesium sulphate	Up to 42
Hydration pressures of sodium sulphate	Up to 48

Ref: Goudie & Viles (1997) Salt Weathering Hazards. Wiley, Chichester.

- **Salt action**. In addition to the disruptive effects arising from repeated cycles of salt crystallisation and hydration (see Table 1 for examples of typical crystallisation and hydration pressures of common salts in comparison to typical tensile strength characteristics of rock) certain salts such as sodium chloride ($NaCl$) readily absorb moisture from the atmosphere when the level of humidity rises above a specific level, a process described as deliquescence. Different deliquescent salts exhibit particular threshold relative humidity values above which they start to deliquesce. These values are called the equilibrium relative humidity (RH) threshold values. Laboratory experimentation on pure salt samples has shown the value of this for sodium chloride to be between 75.1–75.5% over a temperature range of between 0–30°C. Above the equilibrium RH value, these salts will exhibit deliquescence but if the ambient RH falls below this value the salt solution will become saturated and with a continued RH decline salt crystallisation will begin. The significance of deliquescence is that it allows specific salts to remain mobile within stone and also means that repeated cycles of salt crystallisation can be driven by fluctuations in relative humidity.

- Both of the factors outlined above contribute to the physical disruption of stone. However, in addition to this stone is also open to the chemical weathering effect of salt whereby the strongly alkaline conditions (high pH) associated with high salt concentrations can result in the dissolving of certain normally durable elements such as silica (Si) which is a major constituent of minerals such as quartz, feldspar and mica which are common to many stone types. As silica breaks down, the bonds between minerals are destabilised and in some minerals such as mica these chemical changes can lead to the release of iron (Fe), which can form a natural constituent element of mica. The effect of this may become evident in the discolouration and staining of sections of stonework. This form of chemical weathering cannot be reversed.

In lighthouses and associated structures, salt decay is enhanced by the progressive accumulation of marine salts through condensation. The assemblage of salts can be made more complex by the presence of sulphates which give rise to the formation of particularly aggressive salts such as sodium sulphate. Sulphates can be derived from emissions from overcharged lead acid batteries, emission of volatile organic carbons (VOCs) from inadequately sealed fuel tanks or introduced through the use of cement-based mortar repairs.

Basically salt decay is triggered by:

- Salt penetration into surface micro-fractures, between mineral cleavage planes and the joints between individual mineral grains. This penetration is facilitated by prolonged periods of wetness within the towers as a result of condensation or ingress of moisture from an external source.
- Periodic wetting and drying out of stone surfaces leading to salt crystallisation. Depending upon weather conditions and time of year, drying may be diurnal or occur over a period of days. The wetting and drying pattern within lighthouse towers is spatially variable with a tendency for conditions to become drier with increasing height. Although this stratification can be overwritten by the one-off introduction of moisture at higher levels.
- On dry surfaces, crystallised salts can also expand/contract (hydrate/dehydrate) as temperature and relative humidity fluctuate even without actual condensation of moisture.

Since closure of the towers, salt-related deterioration of stonework appears to have accelerated in response to a number of factors:

- Reduced airflow over stone surfaces has decreased evaporation and lead to a significant increase in condensation and hence longer periods of wetness. These longer periods of surface wetness may facilitate salt penetration to greater depths within the stone by keeping salts mobile for a longer time.
- The installation of dehumidifiers has locally accelerated decay by forcing cyclic salt crystallisation. Typically, this is manifest as efflorescence on stone surfaces and associated release of debris.

- Installation of storage heaters can superimpose an additional number of wetting and drying cycles that take advantage of the increased condensation to accelerate the crystallisation of salts at or near the stone surface. Because the capacity of the heaters is limited they tend to have a localised effect with decay concentrated around them.

Within all lighthouses and associated structures, steps should be taken to ensure a consistent airflow as a means of reducing condensation arising from static moisture laden air remaining in contact with cold stone/masonry surfaces for prolonged time periods. To ensure airflow within towers, ventilation will be required at the base and top of each tower but it is recognised that this may require the design of a system shielded from seawater and driven rain. However, an approach of minimum intervention is initially recommended through the use of existing structural characteristics of the tower that can be employed to facilitate improved airflow e.g. opening of old chimney flue systems.

In the planning and implementation of stone management strategies it is important to remember that because of the range of site-specific factors that can influence the extent and severity of stone deterioration, it will be necessary to tailor control measures and/or remedial action to meet the specific needs of each lighthouse rather than searching for a single prescriptive answer.

APPENDIX 4:

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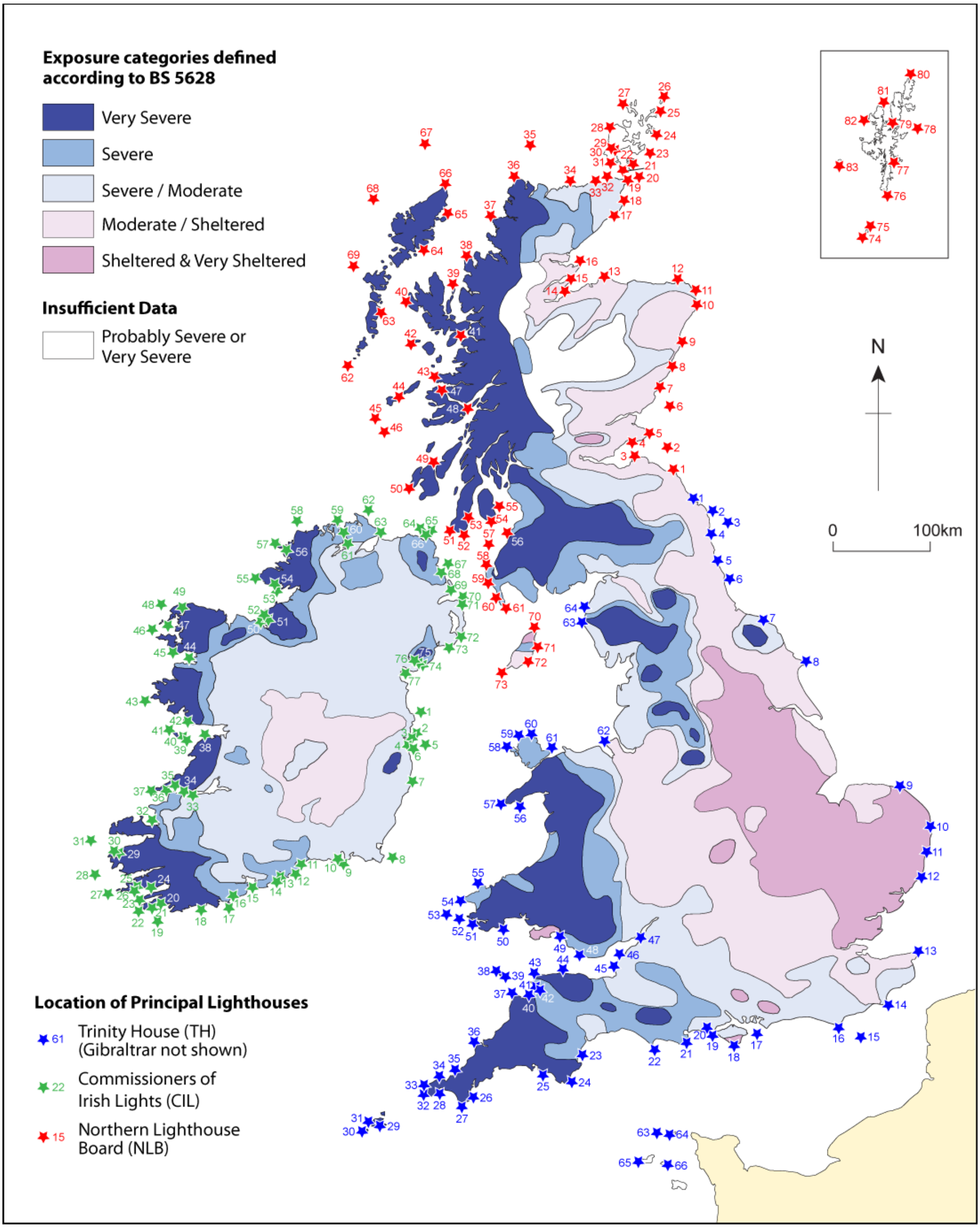
APPENDIX 5:

MAP SHOWING LIGHTHOUSE EXPOSURE CATEGORIES



N.B. This could be doubled in size on a fold-out A3 page