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A New Isothermal System that Avoids the Cold Bridge between the External and Internal Glazing (A Solution Specifically Designed for Extreme Weather Conditions)

Rob MacInnes
ACR, Scotland, UK

Un nouveau système isotherme pour éviter le pont thermique entre les vitres externes et internes (solution conçue spécifiquement pour conditions climatiques extrêmes) – Résumé

60 degrés nord, à la même latitude que l'Alaska, au milieu de la Mer du Nord et de l'Océan Atlantique se trouvent les Îles Shetland, une des régions les plus humides et les plus venteuses de toute l'Europe. Les embruns constants d'eau de mer à 110 km/heure constituent un environnement hostile pour la flore et la faune, les êtres humains et… les vitraux.

À l'intérieur de l'hôtel de ville de Lerwick il se trouve une série unique et entière de beaux vitraux créés par Ballantine d'Édimbourg et Cox Buckley et Cie de Londres. Dans les hôtels de ville britanniques ces vitraux sont presque sans équivalents en ce qui concerne leur récit décoratif. Historic Scotland les a donc revalorisés à son plus haut niveau – classement « A ».

En 2012, Rob McInnes et Linda Cannon ont été engagés par Shetland Islands Council pour remettre en état et pour protéger ces vitraux historiques.

Le vitrage secondaire existant en polycarbonate avec son butyl-mastic synthétique qui avait été installé à la fin des années 1990 avait subi une défaillance complète et il contribuait aux conditions extrêmes de tourbillons de vent entre les panneaux de verre internes et externes. La flexion constante causée par ces tourbillons de vent provoquait des fissures partout dans le plomb et dans le verre. La maçonnerie autour, qui avait été remplacée à la même époque, souffrait beaucoup de la corrosion due au sel et à la pluie battante, ce qui se traduisait par un intérieur creux et alvéolé.

Les systèmes isothermes que nous avions étudiés étaient solides, mais ils ont été rejetés par l'architecte et par les organismes de financement à cause de leur système de pont thermique d'écrous et de boulons lourds et de leur structure solide. On nous a donc demandé de créer un système isotherme sur mesure pour les conditions climatiques extrêmes de Shetland, tout en respectant l'aspect esthétique du bâtiment à l'intérieur comme à l'extérieur. Le système a été conçu pour être ajusté afin de fournir une ventilation optimale pour chaque espce intermédiaire.

Après six ans de recherche et développement, en faisant appel à l'ingénierie de précision allemande et écossaise, et deux ans après l'installation, nous souhaitons présenter notre système breveté au Corpus Vitrearum.

Nous tenons à remercier le Professeur Joost Caen et Leonie Seliger pour leur aide dans la conception et les spécifications techniques.

A New Isothermal System that Avoids the Cold Bridge between the External and Internal Glazing (A Solution Specifically Designed for Extreme Weather Conditions) – Abstract

60 Degrees North, in the same latitude as Alaska, in the middle of the North Sea and the Atlantic Ocean, the Shetland Islands are one of the wettest and windiest parts of Europe. Constant driving salt-water sea spray, and 70 mph winds, provides a hostile environment for flora, fauna, people, and stained glass.

In Lerwick Town Hall there is a beautiful, unique, complete set of 19th-century stained-glass windows by Ballantine of Edinburgh, and Cox Buckley & Co of London. They visually tell the history of the Shetland Islands, and of its Hanseatic past. The windows are almost unparalleled in British Town Halls, as a decorative narrative, and have accordingly been upgraded by Historic Scotland to its highest "A" listing. In 2012, Rob MacInnes and Linda Cannon [Cannon-MacInnes] were instructed by Shetland Islands Council to restore and protect this historic glass.

The existing secondary polycarbonate glazing, and synthetic butyl-mastic bedding compound, which had been installed in the late 1990's, had completely failed, and was contributing to extreme wind-vortex conditions within the glazing interspace. Constant flexing, caused by the vortex, was causing lead-fatigue, and multiple cracks were appearing throughout the glass and the lead. The surrounding stonework, which had also been replaced at the same time, was suffering badly from salt corrosion and driving rain, resulting in a hollow, honeycomb interior.

Traditional isothermal systems which we studied are robust. However, their use of a cold-bridge system of heavy nuts and bolts and solid framework was rejected by both the architect and the funding bodies. We were required to design a bespoke isothermal system for Shetland's extreme weather, whilst being uncompromising in the aesthetic appearance of the building, both inside and out. The system is designed to be adjusted to provide optimum ventilation for each interspace.

After six years of research and development, using German and Scottish precision engineering, and two years since installation, we would like to present our patented system to the Corpus Vitrearum.

We would like to thank Professor Joost Caen and Leonie Seliger for their assistance with the design and technical specifications.

Isothermal Glazing in Shetland

The problem

Cannon-MacInnes Stained Glass [C-M] had annually monitored the unique stained-glass windows in Lerwick Town Hall for three years, from 2012 to 2015, after concerns about the stability of the windows throughout the building were raised. The clients, Shetland Islands Council [SIC], and their architects, Groves Raines Architects of Edinburgh [GRA], asked C-M to closely inspect each window for signs of failure and to remedially stabilise each problem until significant funding could be raised.

The complete glazing scheme of extraordinary Victorian windows [made by Cox Buckley & Co of London, and Ballantine & Co of Edinburgh, between 1883 – 1886] had been previously extensively restored and protected by another stained glass firm in 1997 using a Polycarbonate "glazing" system that had proved to be ineffective in the severe weather conditions. The polycarbonate actively contributed to several ongoing problems. In addition, instead of using traditional lime mortar, the windows had been reinstalled, at this time, using a butyl-mastic bedding compound which had been originally developed for the aircraft manufacturing industry. It produced an adhesive bed which was 'springy' and waterproof. Consequently, the windows 'bounced" on this adhesive and were therefore enduring constant movement. In high winds the leaded panels and the polycarbonate flexed as they were sucked inwards and outwards in a wind vortex created inbetween the polycarbonate and the stained glass. This constant flexing was disastrous for the lead, which was cracking and failing and deteriorating rapidly. The historic glass was noticeably cracking, year after year, as the lead weakened. To make matters worse, the soft sandstone which immediately surrounded each window had also been replaced in the 1990's with a very porous stone from the Cotswolds in the South of England. It was unable to withstand the climactic conditions 700 miles further north and was contributing to the instability of the whole.

After three years of monitoring, it became clear to C-M, the clients, and the architect, that the ongoing deterioration of the windows, and the stonework surrounding them, had to be addressed with the utmost urgency.

Historic Environment Scotland [HES], who are major grant-funders in Scotland, had previously rejected the use of traditional isothermal systems. C-M were therefore commissioned by SIC and GRA to design a bespoke isothermal system, suitable for use in the Town Hall, which would satisfy the rigorous aesthetic and practical specifications which would be acceptable to all involved, and which would withstand frequent extreme weather conditions throughout the year, [Beaufort scale- 11/12]. Thus began a two-year program of research and development, in addition to Cannon-MacInnes' private work elsewhere.

Previous knowledge of existing isothermal systems were well known to C-M; from seeing existing systems in place throughout the UK and Europe, attendance of previous BSMGP, CVMA Colloquia and other conferences since 1987, where the different types of isothermal systems had been discussed and dissected rigorously. C-M also supervised an HES Fellow, Joy Bunclark, in her dissertation of Isothermal Glazing Systems throughout Europe in 2006.

C-M's analysis of the system required for Lerwick fell easily into two groupings: the aesthetic and technical requirements for the external protective windows, and that of the internally suspended leaded glasswork.

Externally there was a number of problems. The system had to be discreet, strong and easily repaired, if necessary. The external windows had to be able to withstand gales on the extreme end of the Beaufort scale, frequent driving rain, and the corrosive effects of seawater. The building was on the top of a small hill and faced vast open stretches of the North Sea and the Atlantic Ocean on three sides. On the fourth side, the windows faced the prevailing winds. All four elevations contained stained glass. Needless to say, the system had to be thoroughly waterproof in all conditions, a feat not achieved since the Town Hall was constructed in the 19th century. From their previous experience of extremely exposed, windy sites in Scotland, C-M realised that any air vent within the system would quickly cause driving rain to pour through and be driven up into the tiniest of gaps. This system had to be completely sealed from the external elements. In this instance, laminate sheet glass was chosen for the protective glazing rather than traditional leaded clear glass, to achieve a smooth completely waterproof surface. Laminate was preferred rather than toughened incase of failure above head-height in a public building.

Internally, the windows were at eye-level. Any system would be seen close up and could be touched. Most isothermal systems are not designed to be seen at quite such close quarters. It had to be elegant. Provision also had to be made for the additional inclusion of toughened protective glass on the inside.

Research & Development

Before C-M began the project, they consulted with colleagues: Professor Joost Caen in Antwerp, and Leonie Seliger, Director of the Cathedral Workshop in Canterbury. They very graciously allowed C-M to look closely at the various systems in use in Antwerp Cathedral, throughout Antwerp itself, and within Canterbury Cathedral. They allowed C-M to discuss with them, and their students and staff, the various strengths and weaknesses of different types of isothermal glazing systems.

During our analysis period, a major potential problem in the systems which we examined, was the inclusion of a metal 'cold bridge' for structural and support reasons. The structural connection between the metalwork in the external windows was to give the internal support metal strength and rigidity. Unfortunately, this also provided a potential 'cold bridge' between the external metal and the internal metal frameworks in the extreme conditions in Shetland. The bridge allowed a temperature difference in the metals touching the internal stained glass, allowing condensation to form and drip onto the leaded glass. The Hall itself was often full of people in the winter, with warm, high humidity inside, and freezing cold outside – the perfect conditions for condensation to occur. They could not allow the potential cold bridge to happen. It was felt that this would be a major weakness in the system given the climactic conditions involved.

They realised that by sealing up the exterior of the windows completely, a different micro-climate would be set up in the interspace in all the windows. They decided, therefore, to make the bespoke system flexible, and adjustable, to ensure that the most effective gap-width was achieved for each elevation.

It was important also, that a robust digital air exchange system was included in the structure of the Hall restoration program, to allow the building to breathe properly, and to restore a relative RH quickly and effectively when the Hall was in use. Cannon-Macinnes handed that particular problem over to the architect.

C-M started designing and developing ideas using a local blacksmith, but soon realised that the individual components had to be precision engineered. They identified an engineering manufacturer in the industrial outskirts of Glasgow who was skilled in producing computer lathe products for the oil industry. C-M produced drawings and scaled sizes for them. Several versions of the 'slide' unit were produced which would be used in our scheme. One was finally chosen and a prototype was produced.

All of the materials used were to be non-ferrous, using manganese bronze, phosphor bronze and brass sections; some off the shelf, some bespoke from the fabricator, some computer-cut and engineered, and some others hand-cut by ourselves on site. The choices between manganese or phosphor bronze were of cost and availability. Internal screws, nuts, washers and bolts were likewise a mix of off-the-shelf non-ferrous items, or precision engineered detailing. Finding or making the right item, and the correct number of items became an interesting question of logistics. Every part of the system was made with flat sections and nuts, screws and washers. Each piece could be individually taken apart without affecting the whole system.

A decision was reached to manufacture a barring system to hold each separate glass panel–in manganese bronze. This allowed C-M to use a material which was aesthetically pleasing and had strength and a discreet elegance suitable for the appearance of the building. It also meant the material could be easily drilled and then screw 'tapped' for comparative ease of production. Both GRA and HES preferred this appearance to the more traditional use of heavy iron bars.

Assembling the system, it quickly became apparent that a locking washer system was required for the slides and the locking nuts. MacInnes selected a locking washer manufactured by the Nordlock Company in Germany. Cannon suggested that C-M get in touch with this company to assess the technical parameters of these locking washers. When he talked to the engineers in Berlin, they asked him "how many thousands of revolutions per minute the locking washers would be subjected to?" When he said, "none", there was a distinct pause whilst the engineer in Berlin decided exactly what he wanted, and how little he knew of materials science. Each pair of interlocking washers had a laser cut, individual number. In case of failure they would be extremely interested in having the parts back. Despite being used in the American space program in the stressful conditions of outer space, no failures had been reported to date. MacInnes brought back the findings, and it was agreed that C-M seemed satisfied that the lock washer system might hold.

After two years R&D, a final 'maquette' was produced for the client, the architect, the funding bodies, and Professor Caen, to allow for comments and improvements before finally going ahead.

Using the system *in situ*

The butyl mastic was impossible to remove from the stone check as it simply stretched and snapped back into the stonework, forcing Cannon-MacInnes to have to cut the stonework itself to release the windows. The leaded glass had a number of problems to be addressed: broken glass, failure of previous epoxy resin joins, failure of plating, weak leads, solder-joint failure, broken ties, loose bars and so on. The glass itself, and the paint, were in good condition. The problems were purely structural, due to the use of inappropriate protective systems and an experimental waterproof bedding compound. The conservation of the stained glass will not be discussed here.

Replacement stone had to be dug by the main contractor's stone masons from a closed quarry in the North of Scotland. Much of the new stone proved to have extensive fault-lines and could not be used. Finding a good stone seam delayed the whole project by months after the removal of the windows. The unexpected extra time gave us more time to problem-solve on site.

Each panel was conserved and bound in shaped "U" channel made of manganese bronze. C-M are grateful to Leonie Seliger and her staff who patiently explained the specific workings of bending, shaping, and finishing the framing work, and to Keith Barley, who sold a job-specific "U" channel bender to enable the recreation of perfect curves and shapes.

By varying the internal width of each horizontal support bar, either a narrow secondary protective glass, or a double width stained glass plus protective toughened glass on the interior could be accommodated within the system. It proved to be extremely flexible in its use.

Finally, the new stones were cut and installed, and the stained glass conservation team worked directly behind the masons, working on each external window until the whole building was secure. The external windows were installed with traditional lime mortar and finished off with a burnt sand mastic and resin "skin" over the surface of the mortar, to keep it watertight. C-M had found, over the years of monitoring the building, that lime mortar pointing itself could not withstand the driving wind and rain in extreme conditions. Unlike the butyl mastic, the lime mortar and mastic skin is easily removed if required and is fully reversible. Importantly, its use, in this way, was also approved by GRA and HES. Each external window panel could now, if necessary, be removed if damaged, without having to remove the whole lancet.

Two different types of precision-cut, slide-bar units were designed and made for Cannon-MacInnes by the engineering firm: one type for the bottom cill (fig. 1), which could be used either vertically or horizontally next to the stonework; and one type for each panel separation going vertically up each lancet (fig. 2). The stone was carefully drilled, and the 'slide units' were attached to the stone ingoes, using high quality marine stainless-steel screws, embedded in a good German nylon/plastic fitting. The new stonework was often wet as the protective scaffold covering was constantly shredding and being blown across the North Sea to Norway. This alone made installation difficult. Care had to be taken with the drilling of holes into the new sandstone to avoid shaling.

The slide system, was incorporated into every part of the internal system, allowed each bar to be adjusted slightly, to achieve a perfect position, up, down, right left, in or out. The use a laser beam and a traditional spirit level, ensured accuracy and precision.

Each window panel varied in size, from approximately 0.2 m/sq to 1.2 m/sq. Although each individual panel was self-supporting, the lower panels also had to bear the additional weight of protective toughened glass up to head height.

Fig. 1. Lerwick Town Hall, Shetland, west elevation detail showing external glazing, mortar covered with burnt sand mastic “skin”, bottom slide bar system placed vertically on stone cill, the leg extension to accommodate any overall height changes, and the lead condensate tray, 2017. © Cannon-MacInnes.

Fig. 2. Lerwick Town Hall, Shetland, west elevation detail showing external glazing, mortar covered with burnt sand mastic “skin”, vertical slide bar system placed vertically on new stone mullion, the manganese bronze support bar, and a fully conserved “middle” panel in place, 2017. © Cannon-MacInnes.

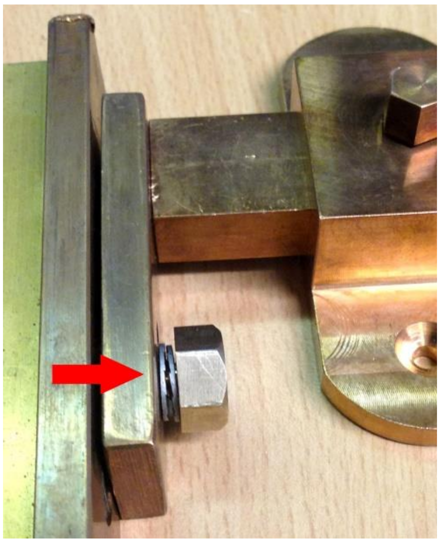

Fig. 3. Lerwick Town Hall, Shetland, detail showing “Nordlock” washers in place within the vertical slide bar system. One pair of washers on each side of the panel ensures the bar will not slip, 2017. © Cannon-MacInnes.

Fig. 4. Lerwick Town Hall, Shetland, south elevation detail showing the internal slide bar, which allows the whole system to be finely tuned to fit perfectly. Each panel can be adjusted on site, slightly up, down, in, out, right or left, 2017. © Cannon-MacInnes.

Each panel was installed in the same way, using one bar top and bottom, and two sliding units, each on either side. The Nordlock washers ensured there was absolutely no slippage once each panel was securely placed in situ (fig.3). Positioning one set of washers on either side of each panel guaranteed that if one washer ever slipped slightly, the opposite set would automatically tighten. Each bar was easily strong enough to bear an adult’s weight on with no apparent effect. We had confidence in installing each panel either from the top down, or the bottom up.

On site, further additions were manufactured to the scheme as required; standard horizontal slot-plates which allowed slight lateral and height movement to visually match the external and internal barring (fig.4), and bespoke vertical slot-plates on the bottom unit, to match the depth of the curved cill. Each additional slot plate was secured using a standard ribbed bronze washer.

We suggested that the glazing system should be monitored for at least a year after installation. It is now three years since completion, and there has been no report of any problems with the glass or the glazing. Although water penetration through the stonework itself is of ongoing concern, this is for the clients and the stonemasons to fix and is not part of the glazing parameters. The mortar and mastic skin remain completely watertight around each window. Lead condensate trays placed on the cill in between the external and internal glass collect any condensate run-off during peak periods. The digital air control system within the room activates above a specific RH and the excess moisture is driven out of the building. This completely sealed glazing system would not function correctly, unless there is an air exchange within the building itself, allowing the building to breathe.

The building has been in use for many popular cultural events, and the circulation of humidity and control of the RH within the room appears to be working well, even on the most overused nights in winter.

Conclusion

The design and manufacture of this slide bar system does not, in any way, negate the successfully tried and tested isothermal systems in use throughout Europe for decades. It may not be ideal for every situation, but its design adds to the overall bank of knowledge on isothermal glazing systems.

This patented system is one solution, to solve a very specific problem; to address the specific requirements of grant-funding bodies, architectural aesthetics, and the extreme weather conditions in Scotland.

The inclusion of internal brass bars increases the overall height of each window exponentially. However, this problem is also one which occurs when using traditional isothermal systems which use heavy "cold-bridge" iron bolts. As with either system, this increase in height can be offset by shaving the top and bottom sections off the lead on each panel.

The slide bar system has been granted a patent: GB2516325.

https://www.ipo.gov.uk/p-find-publication-getPDF.pdf?PatentNo=GB2516325&DocType=B&JournalNumber=6578

As such, any use of this slide bar system should not be copied without the permission of Rab MacInnes.

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Rab MacInnes, ACR
26 Kelvinside Gardens
Glasgow G12 6BB
Scotland, UK
07765 574 967
rob.macinnes@hotmail.co.uk