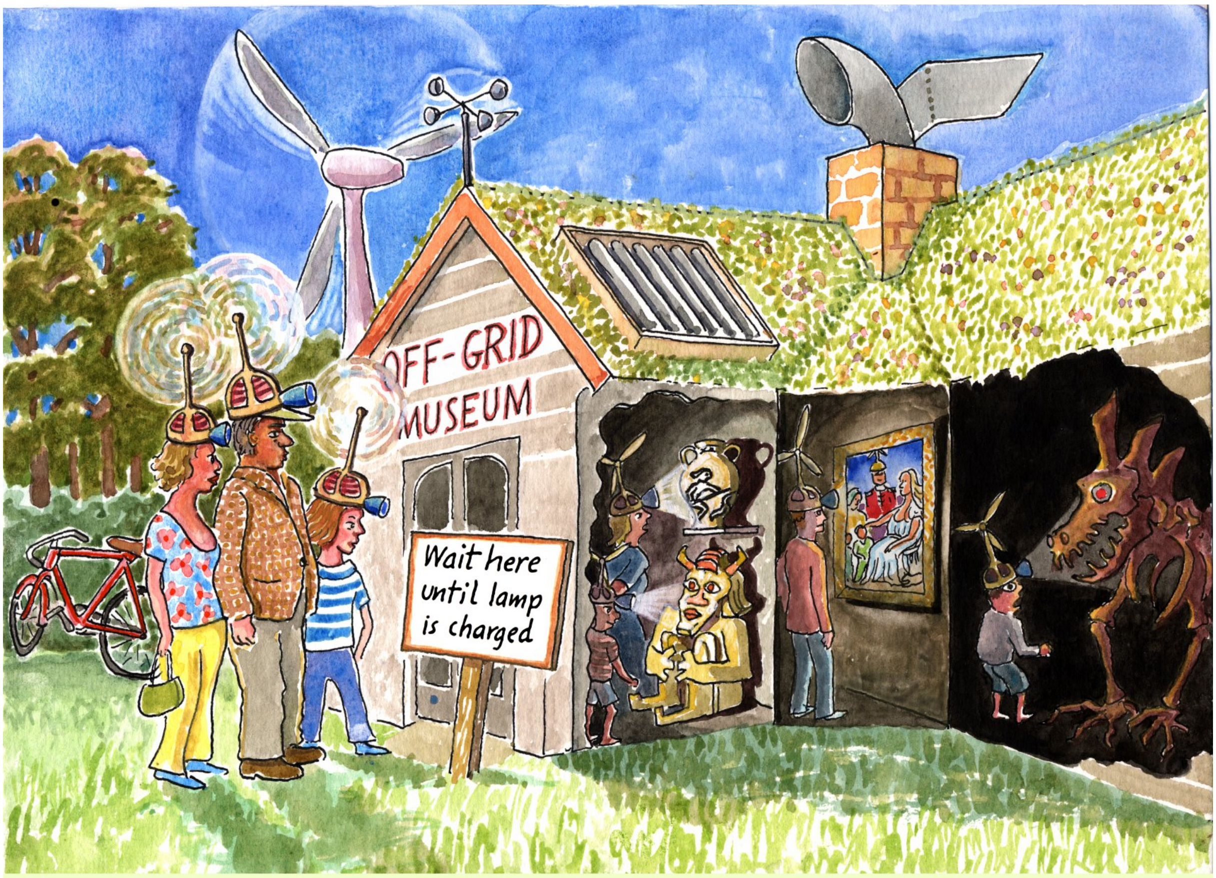

The Off-Grid Museum

Poul Klenz Larsen
Tim Padfield

A lecture given at the Annual Meeting
of the American Institute for Conservation
Philadelphia, 1 June 2011

Low energy museums

Poul Klenz Larsen and Tim Padfield

Summary: Modern museum buildings are among the most energy-hungry public spaces we have. Annual consumption of 400–500 kWh/m^2 is common, even in moderate climates. The running cost is a large part of any museum's budget. It could be used better for exhibitions and research. The museum environment can be controlled entirely by the building itself, supplied only with renewable sources of energy. To achieve this, in most places, we must accept an annual temperature cycle that goes a little beyond the standard range for human comfort and current standards for artifact preservation. Modern museums are much like balloons – very thin structures that depend on pressurized, constantly conditioned air to function. What we propose is the opposite, a building with thick walls to ameliorate the diurnal variation in temperature and with external insulation of a thickness suited to the local climate. The building will have one level and a floor without thermal insulation. This will reduce the annual variation in temperature. The spaces will have a high ceiling to provide a reservoir of air required for human health. This will reduce the need for mechanical ventilation, and allow natural ventilation to assure good air quality. Objects sensitive to relative humidity variation will, as now, be displayed in sealed cases with humidity buffers. The general indoor relative humidity control will in most climates be adjusted by solar powered dehumidification in summer. Natural lighting will be filtered for UV and adjusted in intensity by outside blinds. Supplementary lighting will be provided by LEDs, powered by photovoltaic panels. In most temperate zones there will not be any need for cooling the museum for human comfort. In very hot locations the building will be cooled by solar powered chillers. In cold locations the floor will be heated by a heat pump connected to an underground heat reservoir and powered by a wind turbine. The wind is a very irregular source of energy, so the building must have enough thermal capacity to survive a period without wind. The off-grid museum can be just as spectacular as any architect's dream, without being the conservator's nightmare.

Modern museum buildings depend entirely on external energy resources to function. The reason for this is our desire to control the museum environment. Museum standards require constant levels of light, temperature and humidity, and high ventilation rates. As a consequence museums are among the most energy hungry public spaces we have. What we propose is a museum building which is less dependent on external energy supply and still has sufficient climatic stability. We assert that the museum environment can be controlled mainly by the building itself, aided by energy efficient technology. To achieve this, in most places, we must accept climatic variations beyond the usual range for human comfort and current standards for artifact preservation. The low energy museum can be just as spectacular as any architect's dream without being the conservator's nightmare.

Modern museums are much like balloons - thin structures which needs pressurized air to function. One such example was the temporary shelter for the Nydam boat, an iron age warship which was on loan to the National Museum in Copenhagen some years ago (fig.1). The balloon was rather leaky so the energy used for mechanical air conditioning was large and the climatic stability was poor. However, the climatic insult was nothing compared to the danger when a power cut hit southern Scandinavia for six hours. The balloon collapsed but

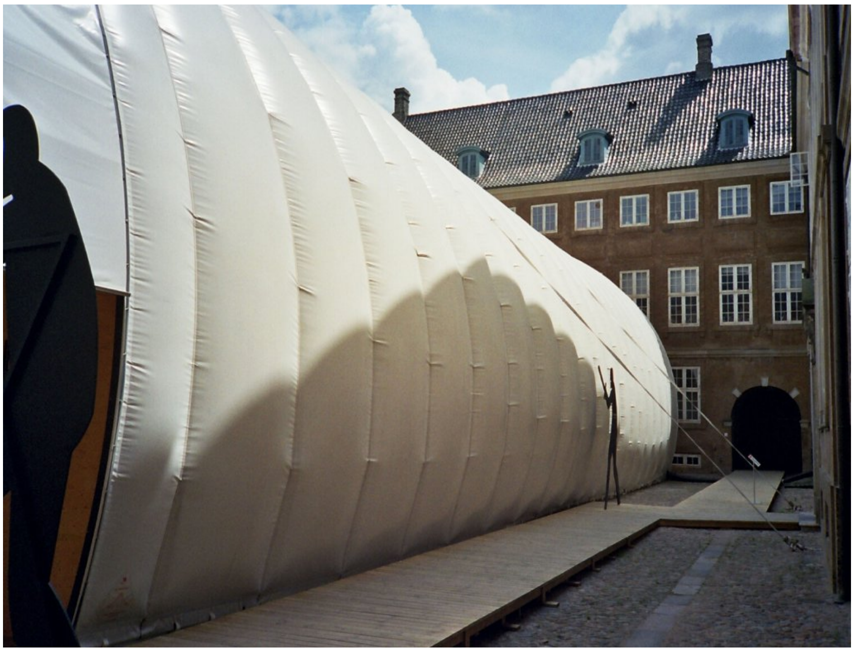

Figure 1: *A temporary shelter for the exhibition of the Nydam Boat, an iron age warship, was designed as a pneumatic structure, located in a courtyard at the National Museum in Copenhagen.*

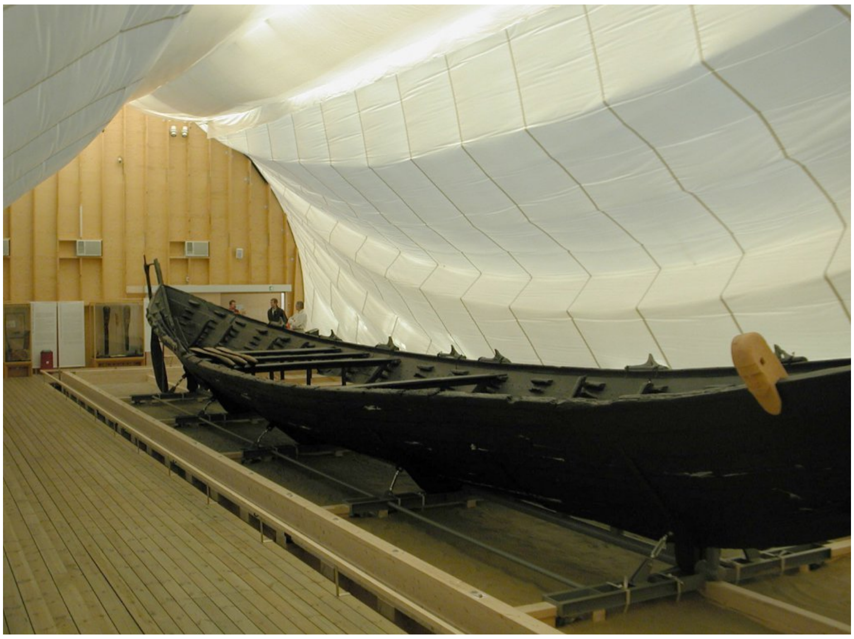

Figure 2: *View of the Nydam Boat as the balloon collapsed due to a 6 hour power cut. Most modern museums depend entirely on external sources of energy to function.*

was fortunately held up by the canopy over the boat, which was suspended by wires to collect condensation (fig.2). Like the balloon, most museums depend on a constant and abundant power supply. We have accustomed ourselves to this luxury during the 20th century, but in the future it may not be so reliable, even in a highly developed society.

The major problem with lightweight buildings is that they tend to become too hot for human comfort in the summer due to the heat injected by solar radiation. Figure 3 shows another relatively thin skinned museum. The submarine was last on active duty in the first Gulf war and is now retired on shore, open to the public. The structure is airtight, as submarines should be, but the interior has no climatic stability. The temperature variations inside are much more extreme than outside, due to solar radiation heating the dark skin. It is raised from the ground, so the floor offers no thermal stability. The relative humidity is even more unstable, because the interior is entirely impermeable to water vapour, so the temperature variations generate huge fluctuations in RH.

The exhibition building for the Imperial War Museum in Manchester (UK) is similar to a submarine, in its natural climate. It has a curved metal roof, which works like a huge solar collector (fig.4). The building is cooled by a conventional air conditioning system, which uses the water in the nearby canal as a heat sink. This method is quite energy efficient, but the annual energy consumption for the building is nevertheless large. It takes a lot of energy to pump enough cold air into the spaces to compensate for the heat gain. Air has little thermal capacity, so the ventilation rate is much higher than needed for human health. It would be simpler to spray the water directly on the roof and have the building cooled by evaporation. Such simple solutions are rarely exploited in modern buildings.

A more sustainable solution is to design the building with heavy walls and insulated roof to moderate the diurnal variation in temperature. This concept was well understood and exploited in early museum buildings, but it seems to have been forgotten in recent museum architecture. The concrete building in figure 5 houses a collection of the works of the Danish sculptor Rudolf Tegner. It is located in a nature reserve and is truly energy neutral. The building has one level and a floor without thermal insulation, which reduces the daily variation in temperature. There is no artificial light, only daylight through the glass roof. The spaces have a high ceiling to provide a reservoir of air required for human health (fig.6). Natural ventilation is sufficient to assure good air quality. The museum is only open to the public in summer, so there is no need for heating.

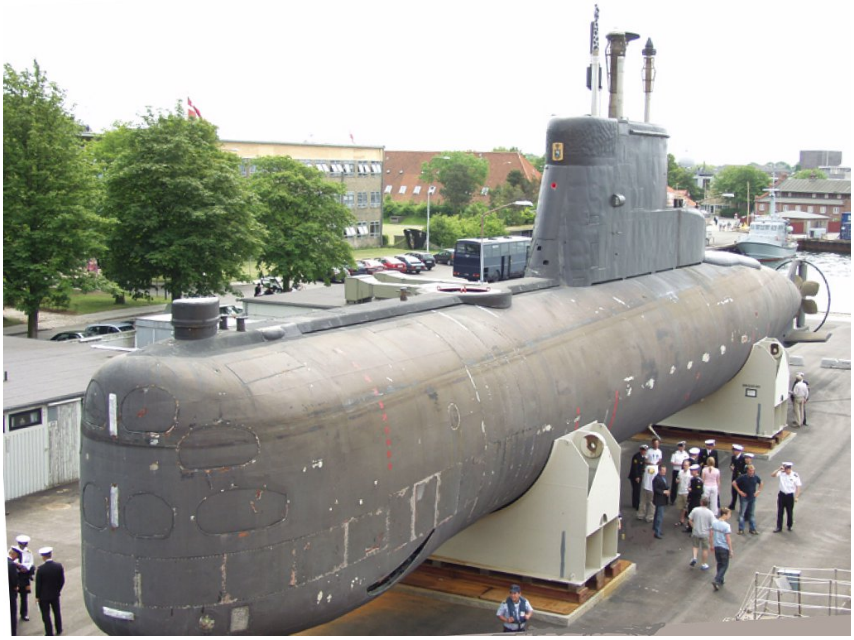

Figure 3: *A submarine at the Copenhagen waterfront, which is now transformed into a museum and open to the public. The inside temperature is very unstable due to heat gain and loss by radiation.*

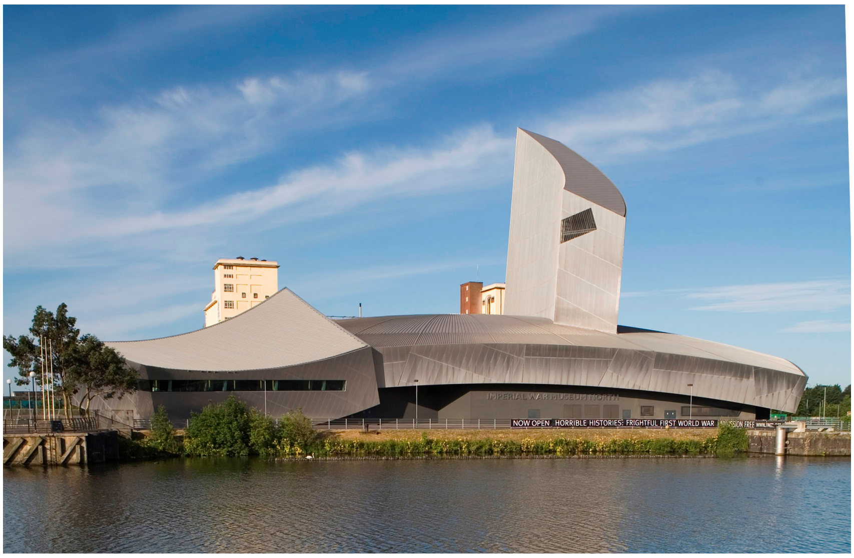

Figure 4: *The exhibition building for the Imperial War Museum in Manchester, UK, is designed much like a submarine. The metal roof is a huge solar collector that heats up the space below in summer. (Courtesy of Imperial War Museum)*

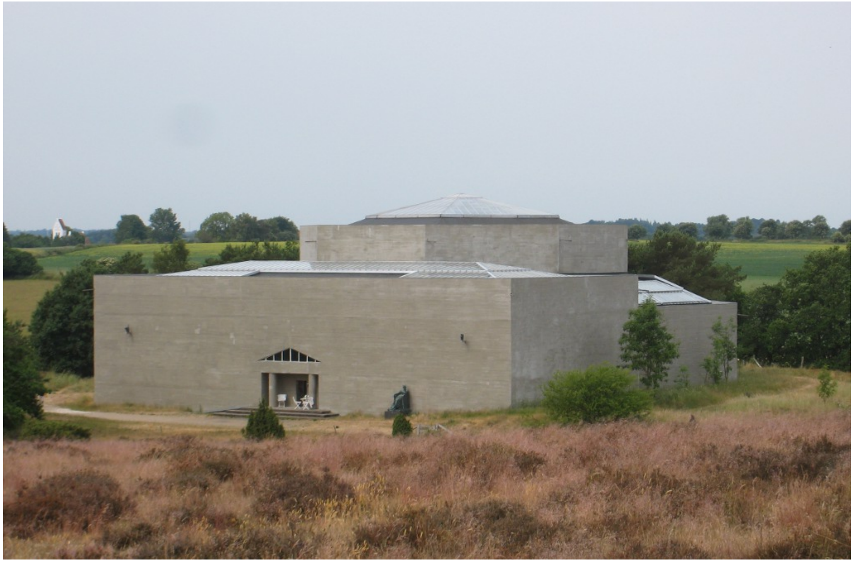

Figure 5: *The Museum for the Danish sculptor Rudolf Tegner is a solid concrete structure located in a nature reserve. It has no external energy supply.*

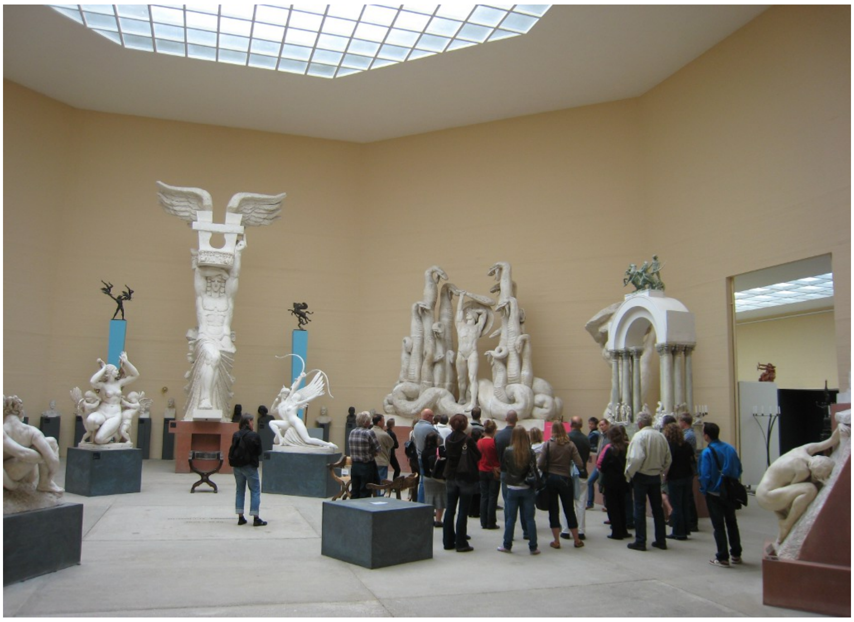

Figure 6: *Rudolf Tegners museum has only natural lighting through the skylights, no heating and no humidity control. It is truly energy neutral.*

There is no humidity control either, so the relative humidity is high most of the year. In this case the objects are robust, but not all museums can be run safely without any climate control.

The house in Liselund Park on the Danish island of Møn, shown in Figure 7, is used as a museum and is open to the public only in the summer. The building is not heated but has dehumidification all the year to keep the RH around 60%. Dry air is injected into each room through small inlets in the floor (fig.8). The temperature follows the outside daily average over the year, from around 0 °C in winter to 20 °C in summer. The humidity control depends on the mechanical dehumidifier. The interior has very poor humidity buffer capacity, because all surfaces are covered with oil paint, so they are almost impermeable to water vapour. The annual energy consumption is 15 MWh or 20 kWh per cubic metre of space. The power load is quite constant over the year, so the dehumidifier needs a reliable source of energy to maintain climatic stability.

In areas with cold winters we need heating for human comfort. The brick masonry building shown in Figure 9 was designed by the Danish artist Per Kirkeby for displaying a collection of minerals. It is heated to moderate temperatures in winter by floor heating served by a heat pump. Although the air temperature inside is down to 14 °C, the thermal comfort is acceptable because feet are kept warm by the brick tiled floor (fig.10). A heat pump is a very energy efficient way to heat a building. This magic machine produces 3 or 4 kWh of heat for every kWh of electricity input. The ground outside the building serves as a heat reservoir that saves the heat from summer to winter. The advantage of a moderate temperature in winter, apart from saving energy, is that the interior RH is also moderate. If the annual temperature variation is kept within 12 – 22 °C, the annual variation of relative humidity is 40 – 60%, which is acceptable for most collections.

In museums heated to modern comfort temperatures, there will be a need for humidification in winter to avoid mechanical damage caused by drying. But there is really no reason to humidify the entire building. Humidity sensitive objects are best protected in carefully sealed display cases. Most museum objects on display are kept behind glass anyway to protect against theft and vandalism, so it is quite convenient to control the RH only inside the sealed boxes instead of controlling the entire building. A humidity buffering material built into the base of the display case will hold the long term average RH in the room. In some situations the humidity buffer provided by the objects is sufficient to control the RH inside the display case (fig.11). Airtight containers have the further ad-

Figure 7: *The country house in the romantic park Liselund has mechanical dehumidification all year to 60%RH. The temperature follows the outside running average.*

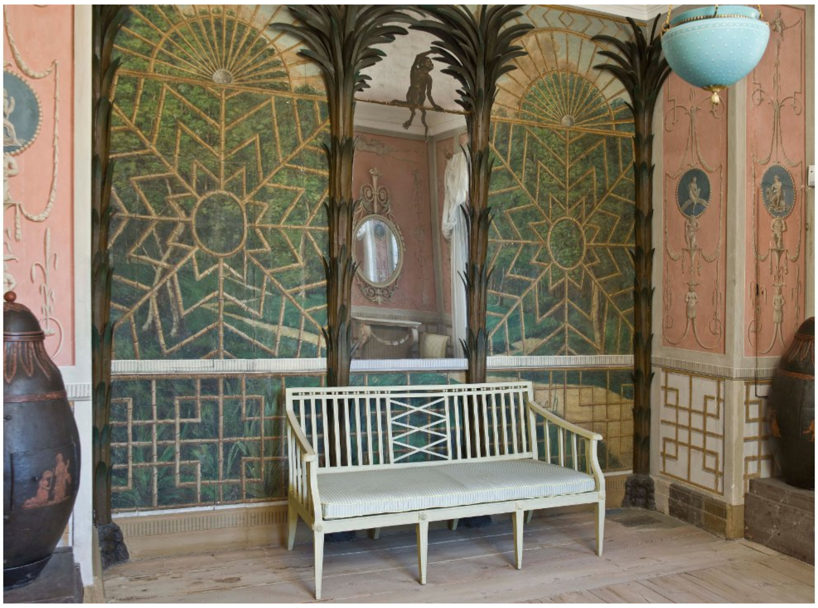

Figure 8: *Interior view of the 'monkey room' in Liselund. The inlet of dry air is through the floor duct in the corner.*

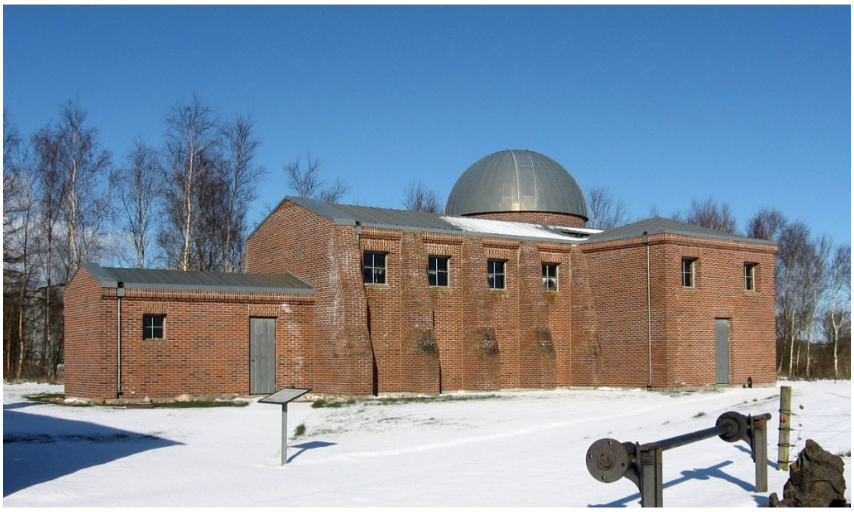

Figure 9: *The 'Stone House' at Skærum Mølle was designed by the artist Per Kirkeby for a collection of minerals. The open land in the front of the building serves as a heat reservoir for the ground source heat pump.*

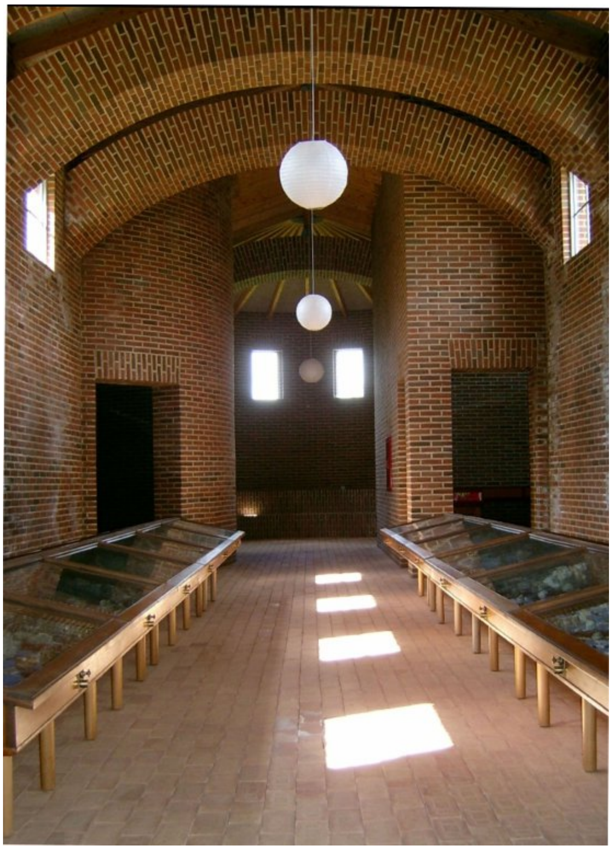

Figure 10: *The Stone House has floor heating to a moderate temperature of 12-14 degrees. The warm floor provides thermal comfort for the visitors.*

Figure 11: *A display case at the Museum of Industrial History in Brede. The paper content will buffer the RH inside the case over the whole year if the leakage rate is low.*

vantage that external pollutants like ozone or nitric acid are excluded, as well as dust and particles. From an energy perspective it is a huge advantage to separate human comfort from the preservation of objects.

Artificial lighting is a substantial part of most museums' energy expense. Incandescent lamps have usually been preferred for exhibitions due to their good colour and contour rendering, but unfortunately this light source is not very energy efficient. Most of the energy is transformed into heat, which sometimes needs to be removed by mechanical cooling. Recent development in LED light offers an energy efficient solution for museum exhibitions. One example is the display of the Royal Jewellery at Rosenborg Castle in Copenhagen (fig.12). For security, the collection is located in an underground vault without any windows. The rooms are lit entirely by white LEDs. The light is built into the display cases to illuminate the treasures without any glare from the glass. The total power load is a few kW, which does not overheat the display case. Such devices have mainly been used for garden lamps until now, but the future will bring LED lighting into the museums.

The ideas presented here have been developed over many years in collaboration with our colleagues at the National Museum of Denmark, Lars Aasbjerg Jensen,

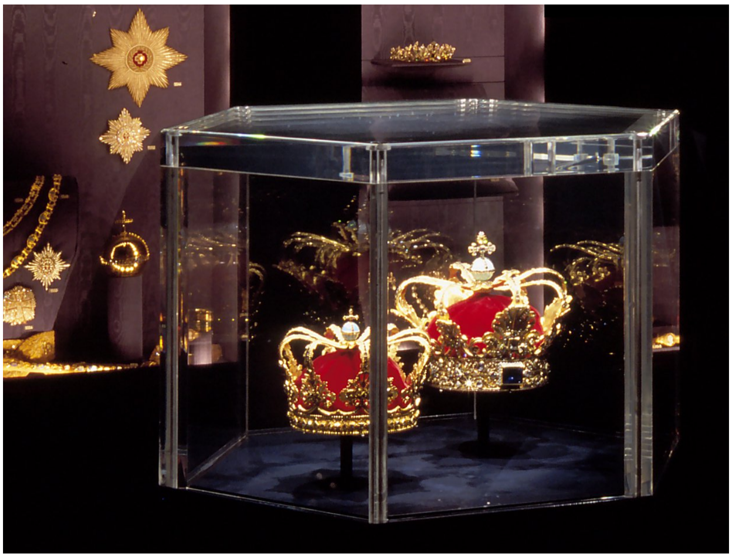

Figure 12: *The underground exhibition of the Royal Jewels at Rosenborg Castle in Copenhagen is illuminated by LED light, mounted inside the display case to avoid reflections in the glass. (Courtesy of Rosenborg Castle)*

Morten Ryhl-Svendsen and Benny Bøhm. This paper is an extended and revised version of the address to the 2011 AIC conference in Philadelphia, USA.

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