The air quality inside the showcase containing the remains of the Danish King St. Knud the Holy (+AD 1086)

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1 Introduction
We have investigated the climate and air quality inside and outside the glass showcase containing a wooden coffin and the remains of the Danish King St. Knud the Holy (+AD 1086), located in Odense Cathedral, Denmark. The reliquary has since 1833 been on display in the church. In 1874 the wooden coffin was placed inside a metal and glass showcase, where it has been kept until this day, i.e. some 137 years (Fig. 1). It contains the Kings bones as well as several textiles, and the wooden 10th century coffin with metal decorations (Rasmussen et al., 1997).

As air contaminants in high concentrations will deteriorate materials, e.g., corrode metals and perish textile (Téterault, 2003), the level of internal air pollution inside the showcase, and the level of climatic interaction between the showcase and the church room, was investigated.

![Fig. 1. The display case containing the reliquary on public display in the church.](image)

2 Materials/Methods
VOC’s were measured inside and outside the showcase for 7 days, using Tenax TA diffusion tubes (prepared and analyzed by Norwegian Institute of Air Research). Organic acids (acetic + formic) were likewise sampled during a 7 days period (IVL Passive Samplers by the Swedish Environmental Institute). Ozone and nitrogen dioxide was sampled for one month; inside the display case, in the church room, and outdoors (diffusion tubes by Gradko International Ltd., United Kingdom). All diffusion sampling was performed in duplicate; the reported concentrations are the average value plus/minus one standard deviation.

At one occasion compounds in air were sampled by exposing a solid-phase microextraction fiber (SPME, type Carboxen/PDMS coating, Supelco Sigma-Aldrich) to the air inside the showcase, and with subsequently analysis by GC/MS. This screening was not qualitative.

The air exchange rate of the showcase was measured at using a CO₂ sensor (2810 Analyzer, Bacharach, Inc., USA) for the measurement of the concentration decay rate of CO₂ released at once into the case from a compressed gas cylinder.

The corrosivity of the air was determined by exposing a 20 x 50 mm pure lead coupon inside the showcase for one year (Merck lead foil 0.25 mm, no. 1.07365.0500 pro analysis). The amount of corrosion was quantified by weighing the coupon on a micro-balance before and after the exposure (Ryhl-Svendsen, 2008).

3 Results and discussion
The main class of pollutants inside the showcase was organic acids; the concentration of formic acid was 270 (±18) µg/m³, and for acetic acid 2550 (±503) µg/m³. VOC’s (other than formic
and acetic acid) were found in a total concentration of 2920 (±573) µg/m³ (toluene equivalents); the main compounds being tridecane, tetradecane, furfural, and acetonitrile. By SPME also monoterpenes and phenoxy derivatives were detected.

While the showcase maintained internally generated compounds in high concentrations, at the same time it retarded external pollutants from entering as the showcase was rather airtight. Ozone, which was present inside the church room at about 5 µg/m³, was below the limit of detection inside the showcase (Fig. 2). The air exchange rate between showcase and church room was 0.8 per day.

![Fig. 2. The distribution of pollutants between showcase, church room, and outdoor.](image)

The lead coupon exposed inside the showcase was after one year totally covered in a whitish corrosion layer. The coupon gained weight corresponding to 8.4 g per m² surface, which, compared to what is observed for normal room conditions, suggests a highly corrosive environment (Ryhl-Svendsen, 2008).

Increased ventilation would retard the build-up of the high pollution level inside the showcase. However, care should be taken at the same time not to increase the ingress of dust. Increased ventilation of the showcase can be achieved by natural air movements (convection) if ventilation holes were added to the case. The glass showcase is placed on top of a wooden plinth, in which a ventilation grille could connect the inside of the showcase with room air. To avoid dust the inside of the plinth should house a filter, which the air stream should pass.

### 4 Conclusions

We find that a viable interpretation is that the organic acids and furfural are derived from off-gassing of the oak wood of the coffin, the monoterpenes from resin in pine wood, and the phenoxy derivatives from the deterioration of lignin.

Air contaminants in high concentrations could pose a potential hazard to the reliquary. The acetic acid could deteriorate metals, the textiles and the bones in the coffin.

Increased ventilation of the showcase would avoid the build-up of internal pollutants inside the showcase.

This study demonstrates how the air pollution concentration may increase to an extreme level in confined spaces, if at the same time a pollution source is enclosed. This is the situation for many museum showcases, e.g., if made of wood.

### 5 References

