**Introduction**

Establishing a proper indoor climate in historic buildings with respect to both comfort and conservation in a non-invasive, sustainable, and energy efficient way pose both practical and scientific challenges. In a conservation perspective, the indoor climate in a historic building is mainly determined by temperature and relative humidity (RH). Common climate related problems in occasionally used historic buildings are high values of RH causing biodegradation and large fluctuations in RH and temperature, often related to heating, causing mechanical damage.

There are two main objectives identified from the state of the art:

- **Intermittent heating**
- **Adaptive ventilation**
- Evaluation of Mould growth prevention with RH reducing measures

**Intermittent heating in massive historic buildings**

**Objective 1** - Propose and validate a methodology for shape-optimization of relative humidity control in historic buildings with regard to heat up time and change rate of RH.

Intermittent heating systems in historic buildings are often manually controlled. The fast increase of temperature during a heating event induces a fast decrease in relative humidity that can be harmful for the building or its interior. A hygro-thermal model for intermittent heating and a control method for limiting large fluctuations in RH at the beginning of the heating event is developed. By controlling the heating time as well as the heating power of a heat-up event, the temperature change rate can be controlled and thereby also the RH change rate.

In the figure, the heat flux (W/m²) due to the supplied heat, \( P_i(W) \), is divided in two main fluxes. The main flux \( P_i(W) \) heats the walls and interiors via the air. The air temperature, \( \Delta T(°C) \), can be modelled by

\[
\Delta T(\tau) = a_0 P_i(t)^2 + b_0 P_i.
\]

Which has the following solution for a step input in \( P_i \):

\[
\Delta T(\tau) = a_0 P_i + b_0 P_i \left( 1 - e^{-\frac{\tau}{\tau_c}} \right).
\]

Parameters \( a_0 \) and \( b_0 \) can be determined by linear regression of air temperature measurements where the temperature is plotted against the square root of time (\( \sqrt{\tau} \)). See figure below. The regression must be conducted on the latter part of the data, when \( \tau > \tau_c \). The time constant \( \tau_c \) can then be found by signal integration of the model.

**Adaptive ventilation**

An AV system lowers the RH in the indoor air by taking advantage of the natural diurnal and seasonal variations in the outside humidity. The outside air is ventilated into a building only when RH is lower than indoor air. The best drying effect is achieved if the building is air tight as the building should also be closed when it is more humid outdoors than indoors.

**Objective 2** - Perform validation and analysis of adaptive ventilation method for relative humidity control in historic buildings.

AV was evaluated in two case studies. The first case study was carried out in an 18th century farm building. The study showed that AV has a significant effect during one year where the RH was significantly reduced in the attic where the RH was above 90%.

The second case study was carried out in a Swedish 13th century stone church. To mitigate the cold air problem described above, an 18th century farm building. The study showed that AV has a significant effect during one year where the RH was significantly reduced in the attic where the RH was above 90%.

**Conclusions**

**Objective 1** - Propose a methodology for non-invasive temperature and humidity control of intermittent heating of massive construction historic buildings

- Simplified thermal and hygro model of massive buildings proposed, together with parameters identification procedure.
- Models validated on measured data at three churches.
- An algorithm for stepped shaping of the heating proposed to avoid risk of high change rate of RH.
- A procedure to determine the overall heating time proposed.

**Objective 2** - Perform validation and analysis of adaptive ventilation method for relative humidity control in historic buildings

- A control system for adaptive ventilation developed and evaluated on two case studies.
- The performed research shows that adaptive ventilation essentially lowers the number of hours of risk for mould growth on a yearly basis, but there is still an increased risk at some short periods when adaptive ventilation is not a sufficient measure.
- It is now possible to simulate AV with either conservation heating or direct dehumidification.

**Objective 3** - Propose and validate adjustments of indoor climate control methods in historic interiors with the focus on the mould growth prevention

- The damage function (LIM 1) for mould growth used to generate a point of RH for mould growth prediction.
- This approach, saves energy compared to constant set-point.
- A three-year case study in Skokloster Castle carried out to compare the methods of RH control to prevent mould growth.
- Direct dehumidification by sorption dehumidifier showed the best result regarding both indoor climate quality in terms of mould risk and stability and energy consumption.
- The mould proofing of the rooms prior to the case study was an important factor in lowering the mould growth risk.

**Key publications**

- Wessberg M, Leijonhufvud G, Broström T. A method to determine heating power distribution determined by the proposed controller.

**Mould control**

**Objective 3** - Propose and validate improvements of indoor climate control in historic interiors with the focus on the mould growth prevention

- Conservation heating, dehumidification and adaptive ventilation can be used to reduce RH in order to reduce mould growth. As energy costs may be high, there is a need to compare these three methods in terms of energy efficiency and mould prevention effectiveness. Traditionally, for these methods the RH set-point is 75% which will result in a higher energy consumption than necessary. By using LIM 1 (Lowest Isopelth for Mould), a set-point strategy can be developed for mould growth control.