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Hygrothermal Evaluation of a Museum Storage Building Based on Actual Measurement and Simulations

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Conservation of cultural heritage objects from chemical, mechanical and biological deterioration is of crucial importance for the modern societies. The optimal preservation of the valuable museum collections in order to ensure their longevity requires a considerable stable indoor environment with slight variations of temperature and relative humidity. According to British Standard 5454:2000 temperature and relative humidity within a museum storage or archive have to be fixed (at a value between 45-60%, 13-16ºC) with minimal tolerances around their set points (5%, 1ºC correspondingly). To obtain such stable indoor environment, extensive air conditioning has to be implemented, which results in significant amounts of energy consumption. However, it has been found that there is a great potential for energy savings by using dehumidification with a safe annual temperature cycle between 10-15ºC. In this regard, in 2003, sixteen regional museums in Western Denmark decided to build a shared museum storage facility just outside Vejle in Denmark.

During 2006 the original construction began its operation and was during 2012 expanded with a new section mainly for storage purposes. DTU Byg has been involved in developing the 2012 storage section in order to ensure even better indoor conditions for the museum collections.

The main idea of the old and the new storage facility was to provide a stable indoor climate, without strong deviations in temperature and relative humidity, while the energy consumption should be negligible. To achieve the aforementioned objectives, it was decided that passive control of the interior environment had to be implemented. The main characteristics of passive conditioning are: *sufficient thermal insulation*, *airtightness of the building envelope* as well as high *thermal and hygric inertia* of the whole structure. A crucial difference between the 2006 and the 2012 storage section is that the new one was designed to be extremely airtight (0.01 ACH as compared to 0.04 ACH for the 2006 storage section) in order to minimize the impact of outdoor weather conditions on the indoor environment. Thick external walls (heavily constructed) and the uninsulated floor provide the required thermal inertia for both storages. More specifically, the uninsulated floor acts as a heater during the winter and as a cooler during the summer months. Additionally, the stored objects as well as the interior leaf of the building walls are responsible for the hygric inertia. To investigate the building's behaviour in terms of temperature levels, simulations are carried out using IDA ICE, and BSim software with actual weather data. Additionally, HEAT2 software is used for heat conduction problems, thermal bridge analysis as well as the calculation of heat losses through the ground.

Broadly speaking, high thermal and hygric inertia should sufficiently stabilize the indoor climate, without mechanical air conditioning. However, it has been observed that the use of auxiliary dehumidification is inevitable in order to maintain relative humidity within the acceptable levels (50±5%). Nevertheless, instead of continuous dehumidification an optimized strategy – "*concentrated dehumidification*" – has been implemented from the beginning of 2014 in the museum storage. Such technique, is applied for a small part during the day (00:00 – 06:00 for the 2006 storage section and 00:00 – 03:00 in the 2012 storage section), while the remaining hours, hygric inertia of the building walls and the stored objects ensure that relative humidity can be left free-running, always within the acceptable levels. Consequently, dehumidifiers are able to use renewable energy. Particularly, excess wind energy during the night can be implemented, transforming the museum storage into a nearly CO_2 neutral building. Additionally, concentrated dehumidification has a significant contribution to handle the inflexible energy produced from Renewable Energy Sources (RES), which constitutes an ambiguous issue nowadays. Dehumidifiers' operation during the night consumes amounts of energy that, otherwise, would either be lost or have to be stored. It should be stated that the implementation of concentrated dehumidification during the night requires a considerable airtight building envelope (similar to the 2012 storage). Hence, infiltration with outdoor air with higher relative humidity, will be minimized and consequently the indoor relative humidity will remain constant.

During the operation of concentrated dehumidification, it is important to examine the hygric interaction of the building walls and the stored objects with the indoor air of the building. Especially for the stored objects, it is necessary to determine the exact value of their moisture buffering effect.

Results based on simulations with IDA ICE and BSim software demonstrate that there is a good agreement between the predicted temperatures and the actual measurements within the museum storage. What is more, it has been found that weather conditions of the previous year affect indoor climate of the building of the following year. As far as the concentrated dehumidification is concerned, it is proved that it constitutes an effective measure for indoor climate stability, especially if it is combined with an extreme airtight building envelope. Regarding the moisture buffer effect of the walls, it has been observed that unpainted walls enhance the stability of relative humidity, whereas use of high moisture resistance paint eliminates the respective ability. Nevertheless, a high airtight building envelope as well as the stored objects minimizes the detrimental effect of paint on walls' moisture buffer contribution.