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Interior insulation – Experimental investigation of hygrothermal conditions and damage evaluation of solid masonry façades in a listed building

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ABSTRACT

Exterior walls in historic multi-storey buildings compared to walls in modern buildings have low thermal resistance, resulting in high energy loss and cold surfaces/floors in cold climates. When restrictions regarding alteration of the exterior appearance exist, interior insulation might be the only possibility to increase occupant comfort.

This paper describes an investigation of the hygrothermal influence when applying 100 mm of diffusion open interior insulation to a historic multi-storey solid masonry spandrel. The dormitory room with the insulated spandrel had a normal indoor climate with a maximum observed monthly average humidity by volume excess of 3.2 g/m^3 during the experiment.

Relative humidity and temperature were monitored manually using wooden dowels over 2 years and 8 months in two solid masonry spandrels: one insulated wall and one untreated wall. The investigation showed that installing insulation on a solid masonry spandrel induced hygrothermal changes: Uniformly distributed higher relative humidity and lower temperature throughout the masonry, compared to an un-insulated wall. The relative humidity of the un-insulated masonry wall was in the range 50% on the inside to 60% on the outside, while the insulated wall showed uniformly distributed values around 80%.

The risk of moisture-induced damage was evaluated based on mathematical models for mould and decay of wood, visual inspection for frost and mould, and on-site measurements for presence of mould spores. The damage evaluation showed no risk of damage from the changed hygrothermal conditions when applying interior insulation to a solid masonry spandrel.

1. Introduction

With today's focus on reducing heat loss, Danish multi-storey buildings with solid masonry walls receive increasing attention due to their large potential for reducing heat loss and consequent reduction of CO_2 emissions [1,2]. The overall heat loss can be simplified to a vertical component through roof and ground, and a horizontal component through the façade, including the gables when exposed. Research shows that considerable energy savings can be achieved by applying thermal insulation to the solid masonry walls of historic multi-storey buildings [3,4]. The spandrels underneath the windows are the thinnest walls in traditional multi-story buildings and are responsible for a considerable part in the overall heat loss of the facade. The walls are characteristically 1-stone thick (238 mm), and have an interior layer of plaster [5,6]. 1-D hygrothermal simulation in WUFI of an uninsulated spandrel showed a minimum temperature on the inside of 9.2 °C [7] when simulating with a Danish design year [8]. Occupants staying in rooms with cold surfaces can suffer from discomfort due to asymmetric radiation from surfaces when larger than 10 °C [9,10], cold floors [11,12] and draught. Occupant comfort will increase, when the exposure to cold surfaces are reduced.

From a building physics point of view, the best location for adding insulation to a solid masonry wall is on the exterior side [13–15]. However, from a building preservation point of view, exterior insulation is often not a possibility. E.g., preservation of the exterior appearance of listed and worth-to-preserve buildings is a mandatory requirement in Denmark. With worth-to-preserve buildings, interior insulation is therefore often the only possibility.

Previous research has focused on how to add interior insulation on old masonry structures and the performance of the insulation material [3,16–22]. Aiming for energy reduction and temperature increase of the thinnest parts of the façade, Odgaard et al. showed that for a multi-storey building with 2-stone (468 mm) wall columns with interior rendering, up to 40% of the possible U-value reduction by applying

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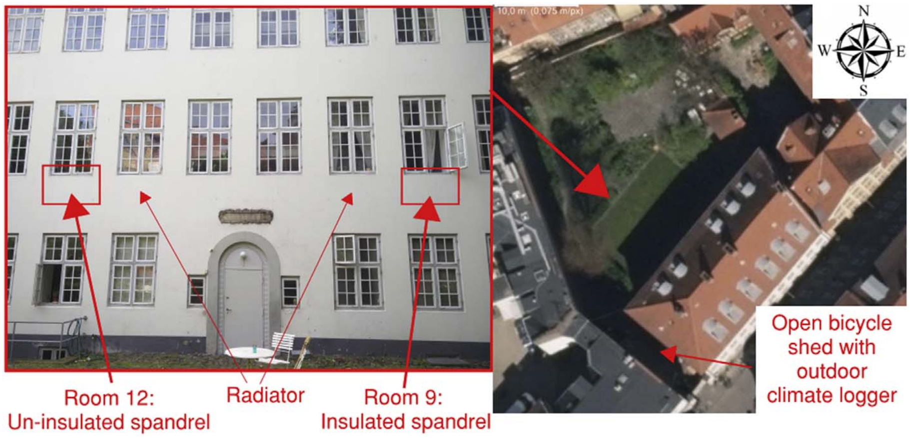

Fig. 1. Picture of façade used in experiment. Overview courtesy of Maps from COWI.

interior insulation to the entire interior masonry wall, could be achieved by insulating the spandrels [23].

Hygrothermal conditions in the original solid masonry wall become worse when adding thermal insulation to the interior side. The heat flow from the room to the original wall will be reduced [24], possibly causing condensation to form behind vapour open insulation [15,25]. The moisture content increases in the original wall, and leads to high moisture content on the cold side of the newly added insulation material [15,22,24,26–29].

The changed hygrothermal conditions will increase the risk of damages. One being the risk of frost damage [15], governed by 3 criteria occurring at the same time [30]: Temperature below freezing; wet masonry; and material sensitivity to frost. Another being the risk of mould and decay of wood occurring, governed by Ref. [31]: temperature; relative humidity; exposure time; and material.

Mould risk can be assessed mathematically based on monitored relative humidity and temperature, or based on on-site measurements. A large amount of different mathematical mould models exist in literature. Comparison of models have previously been done in Ref. [32] for wood, whereas review of the models including other material surfaces were included in Ref. [33]. A transfer model that converts the “growth-in-mm" results from the bio-hygrothermal model of Sedlbauer [34,35], the model used in WUFI, to the mould index model developed by Ojanen et al. [36], the model used in Delphin were described in Ref. [37]. Mathematical mould risk evaluation in this paper was based on the model from VTT [36,38], with risk evaluation based on the defined limits for maximum allowed mould index values at the interior side and interstices in the structure [37]. Different approaches for on-site measurements exist [39–41]. As the aim of present investigation is to detect if mould growth occurs, and not to detect specific mould species, it was decided to use the Mycometer®-test method [42].

A review of different mathematical decay models were performed by Brischke and Thelandersson, with a focus on outdoor conditions. As the models were based on temperature, relative humidity and exposure time, the models must also be appropriate for wood performance in other positions where oxygen is available. A range of parameters, which should be included in an appropriate model for decay of wood, were described in Ref. [43]: The importance of wood type, the need for inclusion of lag/activation process and how dose-response functions are appropriate for the biological field. The model of H. Viitanen et al. [44] included the mentioned parameters, where the inclusion of the activation process, defined as an index "α", resulted in a dose-response function that comprises the lag effect. The model in Ref. [44] was based on Pine Sapwood, the structural lumber in historic Danish Multi-storey buildings traditionally consist of Pomeranian Pinewood, both heartwood and sapwood [5,6]. Oxygen will be naturally present in the traditional floor constructions of historic multi-storey buildings, which consist of layers of open air and clay.

Hygrothermal conditions in the experiment were monitored using wooden dowels drilled into the walls of interest. The use of wooden dowels to monitor hygrothermal conditions in structures is well-known and has proven as a stable methodology for long-term measurements [45–47], with examples of sensors working for a minimum of 20 years [48]. The conversion of resistance and temperature measurements in wooden dowels to wood moisture content is described both in Danish [49–52] and international literature stating the applicability of wooden dowels for slow and long term-measurement of relative humidity [53,54].

The aim of this paper is to present the results of an investigation of changed hygrothermal conditions when applying interior insulation to a reduced part of the interior surface, specifically the spandrels of a historic solid masonry wall. This has been conducted experimentally by installing interior insulation in the old historic Borchs Dormitory from 1823, situated in the Danish capital, Copenhagen. The dormitory consists of solid masonry walls with a rendered and painted facade. The study focused on reduction of heat loss and improvement of the indoor climate without risk of damage by frost, mould or decay of wood. The hygrothermal conditions were monitored in two walls, one with and one without interior insulation. Døi and Nielsen started the monitoring period in November 2014 with 1½ months of measurements [55]. The hygrothermal conditions continued to be monitored as reported in the present study, and comprises a total monitoring period of 2 years and 8 months.

2. Method

2.1. Experimental setup - building composition

Borchs dormitory was built in year 1823 and is situated at the coordinates (55.6805°N, 12.5744°E). A picture of the façade and overview of the area can be seen in Fig. 1. The buildings north and northwest of the garden/courtyard in front of the façade have a height of 4–5 stories + roof, which limits the influence from dominant western winds and wind driven rain. The exterior façade consists of solid masonry walls, constructed from historic red clay bricks and lime mortar, with no built in thermal insulation. The windows do not have an external sill. The position of the windows follow building tradition, situated approximately 4 cm from the exterior surface into the building, leaving 4 cm of masonry at the bottom, top and sides of the wall around the window exposed to rain. The infiltration of rainwater is reduced by a layer of rendering and paint covering the exterior side of the masonry wall. This rendering was originally performed with lime mortar, which might have been repaired with rendering systems with content of Portland cement at later stages. The masonry wall is also rendered and painted on the interior side. The building has four storeys, three of which have rendered and painted vertical facades and a 4th storey