Building and Environment 95 (2016) 272–282

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Hygrothermal conditions in cold, north facing attic spaces under the eaves with vapour-open roofing underlay in a cool, temperate climate

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A R T I C L E I N F O

Article history:
Received 28 May 2015
Received in revised form
7 September 2015
Accepted 9 September 2015
Available online 11 September 2015

Keywords:
Cold attics
Ventilation
Vapour-open roofing underlay
Moisture
Vapour condensation
Building physics

A B S T R A C T

Measurements of relative humidity and temperature in eight cold attic spaces under the eaves with varying infiltration and passive ventilation strategies were carried out in a full-scale experimental setup in Denmark. The research project tests whether best practice recommendations given to ensure compliance with the current Danish Building Regulations (BR10) for airtightness (<1.5 l/m^2 s at 50 Pa pressure difference) can ensure acceptable moisture levels in attics with vapour-open roofing underlays. North facing cold attic spaces under the eaves constitute a worst case scenario.

Following best practice recommendations concerning ventilation of the cold attic space under the eaves and fulfilling the requirements in BR10 regarding air tightness of the building envelope did not ensure the absence of mould growth in the attics. Through winter the attics with infiltration through leaks (dimensioned to allow an influx of 3.3 l/s of conditioned indoor air 20 °C and 60% RH at a pressure difference of 50 Pa) and ventilation (singled-sided, passive ventilation) contained more moisture and had significantly higher levels of mould growth than the non-ventilated attics. Under the same physical conditions the 'pressure equalized' attic rooms were found to have moisture levels in between those observed in the ventilated and non-ventilated attic rooms. Likewise, the observed levels of mould growth were in between those observed in the cases of the ventilated and non-ventilated attic rooms. Attics with reduced infiltration were not seen to display lower moisture levels but did show lower but still significant levels of mould growth.

1. Introduction

The general recommendation in temperate climates is that cold attics should be ventilated by outdoor air and that cold attics should be constructed air- and vapour-tight to the heated area. However, moisture related problems such as mould growth can still be found in attics even when local guidelines on best practice have been followed [1–5]. Research into moisture related problems in attics have sought to determine the root causes of the problems and have tested design solutions to rid attic environments of damaging moisture conditions. Studies have been conducted on various different attic construction designs and using different success criteria making direct comparison between conclusions challenging.

Experimental studies in full scale setups conducted in Sweden have found that a reduction of the volume of outdoor air used for ventilation of attic environments can help reduce the moisture levels in an attic environment [1,6]. Similarly, a Norwegian study that used computational analysis to examine the possibilities of using vapour-open roofing underlays in unventilated attic rooms concluded that this is possible, as long as the vapour resistance of the roofing underlay is sufficiently low [4]. Another study, based on computational simulations done in HAM-tools [7] for weather conditions in the south-west of Sweden, found that naturally ventilated attic environments in all tested cases fulfilled the criteria for mould growth and stated that outdoor air in a cool, humid climate is a source of moisture in itself [8]. On the face of things, the findings of [8] supported the hypothesis of the studies [1,6], but does not appear to be in agreement with study [4]. A Scottish study using HAM tools [3] and a German study of a full scale setup [9] both found that ventilation reduced the amount of water

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http://dx.doi.org/10.1016/j.buildenv.2015.09.009
0360-1323/

condensate on the roofing underlay without entirely removing it and are therefore apparently in disagreement with all of the first mentioned studies [1,4,6]. Other studies, in turn, hypothesize that attic ventilation can be useful for removing excess moisture, but that this is dependent on the type of local climate [10,11]. Meanwhile, a design using mechanical, adaptive ventilation, that only ventilates when exterior absolute moisture levels are lower than attic absolute levels, to reduce moisture concentrations in attics below critical levels, which is 75% RH (independent of temperature) [12,13], has been successfully tested [14] seemingly proving that ventilation can help, if implemented properly. Alternatively, other studies suggest, it is possible to influence and lower cold attic RH by maintaining a low relative humidity in the conditioned zone [15,16].

As shown above, the review of literature published on the subject shows that findings from different studies, or at least the interpretations of these findings, are not always in agreement with one another leaving room for more work in the field.

2. Experimental setup and method

This paper presents an experimental study of passive ventilation strategies for cold attic spaces under the eaves with vapour-open roofing underlays. Measurements of relative humidity and temperature in eight cold attic rooms with varying infiltration of conditioned air (20 °C and 60% RH) and passive ventilation strategies were carried out. Subsequently an assessment of mould growth in the attic was made. The 60% indoor relative humidity and 20 °C indoor temperature (corresponding to a water vapour content of 10 g/m^3) was chosen in accordance with prior Danish indoor climate class 2 (dwellings, offices, schools, institutions, industry without moisture production) used for hygrothermal design of roof constructions [17]. The research project work includes testing of whether best practice recommendations regarding ventilation of attics in combination with the requirements in Danish Building Regulations 2010 [18] for airtightness (less than 1.5 l/s per heated m^2 floor area at 50 Pa pressure difference) ensure acceptable moisture levels in attics with vapour-open roofing underlays. To this end a full-scale experimental setup was built on the test grounds of the Department of Civil Engineering at the Technical University of Denmark. North facing cold attic spaces under the eaves is the worst case scenario simulated in the experimental setup.

The project tests the conditions in attic spaces with a floor width <1 m which, according to the 2nd edition of SBi Guidelines 224 (2013) [19], do not need to be ventilated: "It cannot be expected that vapour-open roofing underlays – $Z \leq 3$ GPa m^2 s/kg – can satisfactorily remove moisture from attics with a floor width >1 m. Unless the vapour barrier is perfectly implemented, 'modest ventilation' must be established when using vapour-open roofing underlays e.g. by vents or gaps in every second truss in attics, spaces over the collar beams and spaces under the eaves." The previous edition of the Danish SBi Guidelines 224 (2009) [20] describes the minimum requirement for ventilation as 'pressure equalisation'; this type of design has also been tested.

The experimental setup is located at the test grounds of The Department of Civil Engineering at The Technical University of Denmark in Lyngby, Denmark (55° 47′ 9.26″ N, 12° 31′ 23.83″ E). The measurements were made in the period from November 2010 to February 2013.

The test facility is constructed from a used 40 foot insulated reefer container fitted with a lean-to roof. The lean-to roof is segmented into eight separate cold attic rooms. The cold attic rooms are constructed in such a way that they each have distinctive features that are designed to simulate different structural scenarios.

Table 1
Overview of attic room features in experimental setup.

Attic room	Infiltration	Ventilation valve	Pressure equalisation valve
1	–	–	–
2	–	–	+
3	–	+	+
4	100%	–	–
5	100%	–	+
6	100%	+	+
7	40%	–	+
8	40%	+	+

All of them are fitted with a vapour-open roofing underlay. The experimental attics are facing north and this way gets a minimum of direct sunlight. For this reason the relative humidity levels in these attics is expected to be higher than in attics facing other directions.

The experimental setup was designed to investigate the significance of infiltration and ventilation in cold attic spaces. The setup has three series of attic rooms: One without infiltration from the conditioned container, one with 2.25 l/s at 50 Pa pressure difference (100%) and one with 0.9 l/s at 50 Pa pressure difference (40%). The series are build up as having one room with no ventilation studs (airtight), one with one ventilation stud in the top corner of the roofing underlay (pressure equalised) and one with two ventilation studs where one is in the top corner and the other diagonally below it in the bottom corner (single-sided ventilation). The series with reduced ventilation does not have a room with singled-sided ventilation (Table 1).

2.1. Construction

Special attention has been given to make the separate construction parts impermeable for air and vapour flows. Also, there has been a focused effort to avoid built-in moisture; the wood was dried and the experimental setup was covered during construction.

The 8 cold attics have interior dimensions (L x W x H) 1.5 × 1 × 1 m. The indoor air (inside the container) was maintained at 20 °C and 60% relative humidity. A humidifier and convectors

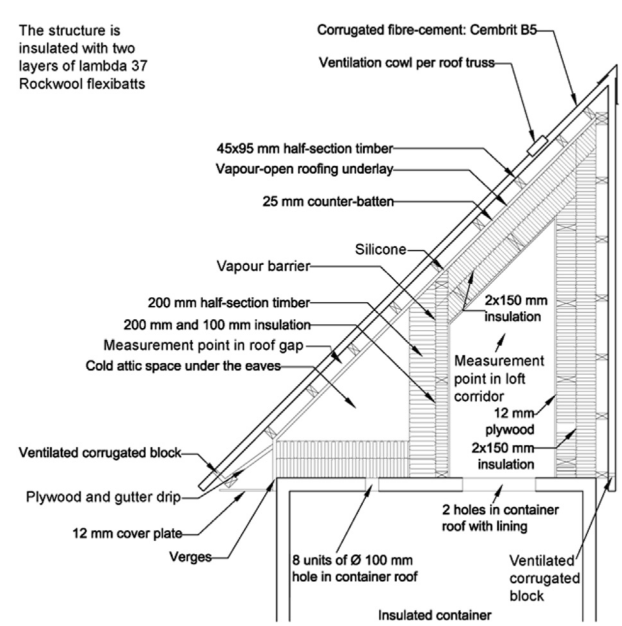

Fig. 1. Vertical section of the experimental setup.