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Influences on the drying behavior of a concrete ceiling below a cold attic

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Influences on the drying behavior of a concrete ceiling below a cold attic.

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Abstract. The article describes the current state of a project examining the influences on the moisture distribution in cold attics above concrete ceilings of residential buildings. Considerable research has been done on moisture damages in cold attics, especially in Scandinavia and North America, focussing on spaces above wooden ceilings. The project (ongoing until Sept 2021) underlying the article deals with cold attics above concrete ceilings resting on masonry walls, a frequent variant in Austria. Research was triggered by a regional Austrian building industry association to shed light onto recent detrimental moisture accumulation in the wooden wall plate (= bearing for the rafters along the eaves) and in the two EPS insulation layers on top of the ceiling. Suspected reasons for the moisture problems and for the local moisture distribution are 1) a too small diffusion resistance of the vapour retarder covering the ceiling, 2) insufficient (natural) attic ventilation and 3) convection, e. g. in the gap between the polystyrene blocks. In order to rank these potential causes by influence and also to find a practical solution a two stage experimental approach was chosen: 1) A handy small scale replica (order of dimension: 1m) of the situation was exposed to the according indoor and outdoor climate in a climate chamber. Different vapour retarders on top of the ceiling were chosen. 2) A larger 1:1 replica has been erected as well but not yet delivered monitoring data. In parallel, a hygrothermic model taking convection into account was established and simulations carried out. The project will deliver a contribution to the Austrian standard on moisture safety 8110-2 on how to judge the moisture safety of joints via simulation.

1. Background

The current article describes intermediate results from an ongoing project. It was triggered by moisture problems found in Austria in cold attics of single family houses under a rafter roof above a concrete ceiling covered by polystyrene insulation.

Excess dampness and mould was described by a construction company to be repeatedly found

(i) at the inferior purlin and there in particular at the heads of the steel bolts used for screwing the purlin against the concrete ceiling

(ii) at the surfaces of the gaps between adjacent polystyrene insulation panels

The research project goals are

(i) to understand moisture transport phenomena around the region of the inferior purlin, embedded in the insulation layer

(ii) to understand the reasons for the observed damages and establishing guiding principles for construction companies
(iii) to improve the features for modelling convection in cracks and gaps of an existing HAM software "HAM4D_VIE". HAM4D_VIE was validated on air convection in [4] and in [2].

The influencing factors of the moisture content of the cold attic above a concrete slab shall be examined stepwise. In a first approach only the influence of the sd-value of the vapour retarder on the slab was examined and compared against simulation. Special attention was given to the data in and around the drilling holes of the steel bolts which are fixing the purlin against the slab.

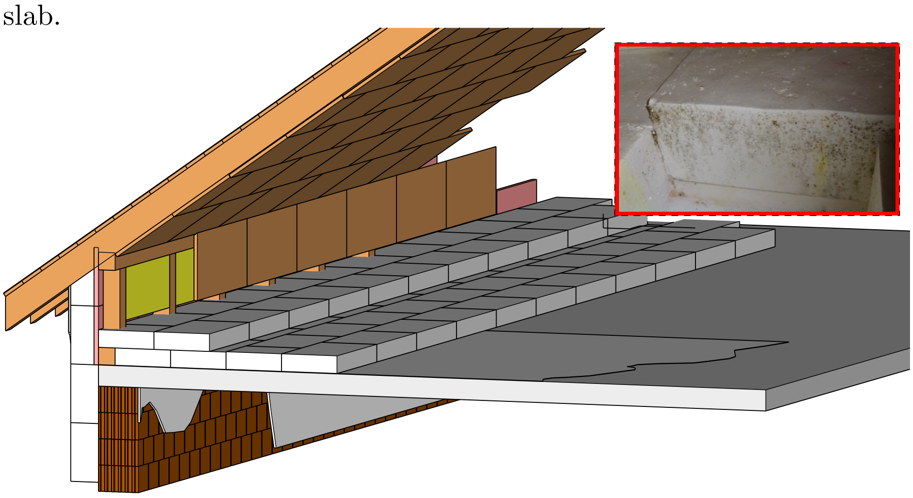

Fig. 1.1: Model of the cold attic that triggered the current project. To the difference of the experimental setup (which represents the majority of such cases in practice) in the figure rafters rest on a purlin that is elevated on studs which rest on a beam and the roof has an inner sheathing. Top right: Mould formed between EPS layers in the original building.

2. Cold attics

The most comprehensive and most recent literature overview on relevant works on cold attics is given in [18]. Most studies bear on lightweight wooden beam ceilings separating the attic from the conditioned room below. In such a case convection from the warm inner side to the cold attic during the heating period is usually the dominant moisture transport path from the warm to the cold side ([10]). Due to the filling and flowing nature of fresh concrete the risk of convection is much reduced with a concrete slab as a ceiling, in particular if, as in the current case, access to the attic is not through the ceiling but from the outside.

Influencing factors on the average moisture content inside the cold attic are:

(i) *user behaviour* and thus moisture load from the room below the cold attic ([19], [12])
(ii) *air tightness* between cold attic and the conditioned room below. This includes flanking air paths through the hollow brick masonry and through gaps between wall layers and in the region where wall, ceiling and rafters/purlin join. ([13], summary in [18])
(iii) *ventilation* of the cold attic ([17], [8], [16]). However unfavourable conditions during ventilation (leaky ceiling to the room below the cold attic, outdoor higher than indoor humidity) may also worsen the situation ([12], [7], [8])
(iv) *placement of the ventilation openings* in case of natural ventilation ([13])
(v) *sd-value of the outer hull* of the cold attic ([19])

(vi) the usage of a *vapour retarder in the ceiling*, however [9] showed a negligible influence of the moisture load on a well ventilated attic – for wooden ceilings.

(vii) the *building orientation* ([17])

(viii) *built-in-damp of the wood* ([7])

3. Description of the experiment

Small replica A 1:1 replica of the detail around the purlin was built (**Fig. 3.1**) with around 60 sensors and 90 datapoints (temperature and moisture) placed along three longitudinal axes in order to assess also boundary effects. A digital temperature/humidity sensor HYT-939 of the manufacturer IST with a precision of ±1,8% rh, temperature ± 0,2 °C and a pt1000-sensor (Heraeus M 222) were used for temperature only measurements.
The replica was placed in a climate chamber conditioned at 2 °C, moisture content was not controlled. A ventilator in the chamber homogenized air conditions spatially. The replica was thermally insulated at five sides with 20 cm phenolic foam/XPS panels and covered with a batt of negligible sd-value in order to avoid the fan to induce air movement in the monitored region. The slab was heated from below via a heating mat with a thermostat mocking a room conditioned at 26 °C. Air gaps of 2 mm thickness were kept via washers between the EPS panels taking account of real conditions at the construction site. The purlin was used wood taken from a construction site, moisture content was not measured. The purlin was screwed to the sufficiently hardened concrete slab via drilling holes filled with glue (in reality, sometimes the bolts are already mounted before the concrete is poured). Cavities for the bolt heads were cut into the EPS panel resting on the purlin. This detail is laboratory specific; at the construction site consequently larger air gaps above the purlin will result. Below the purlin a bituminous waterproof sealant was placed protruding below the purlin for some centimeters and then air tight connected via tape to the vapour retarder which covered the entire slab. The sd-values of the retarders were taken from manufacturer product sheets. Air could theoretically flow through the air gaps between the EPS panels. The panels were sealed with silicone air tight against the flanking walls (see **Fig. 3.1**) in order to exclude boundary effects with regard to the real situation (real building).

Two variants of the experiments were established regarding the sd-value of the vapour barrier on top of the concrete slab:

(i) *case A:* sd-value ≈ 0.2 m → diffusion open, placement in the climate chamber on 2020-10-16, opening on 2020-12-10 and

(ii) *case B:* sd-value > 100 m → rather diffusion tight, placement in the climate chamber on 2021-01-14, opening on 2021-02-25. In this latter variant, the air gaps on top of the EPS panels were partly sealed with tapes for a limited time to better understand the air flow regime.

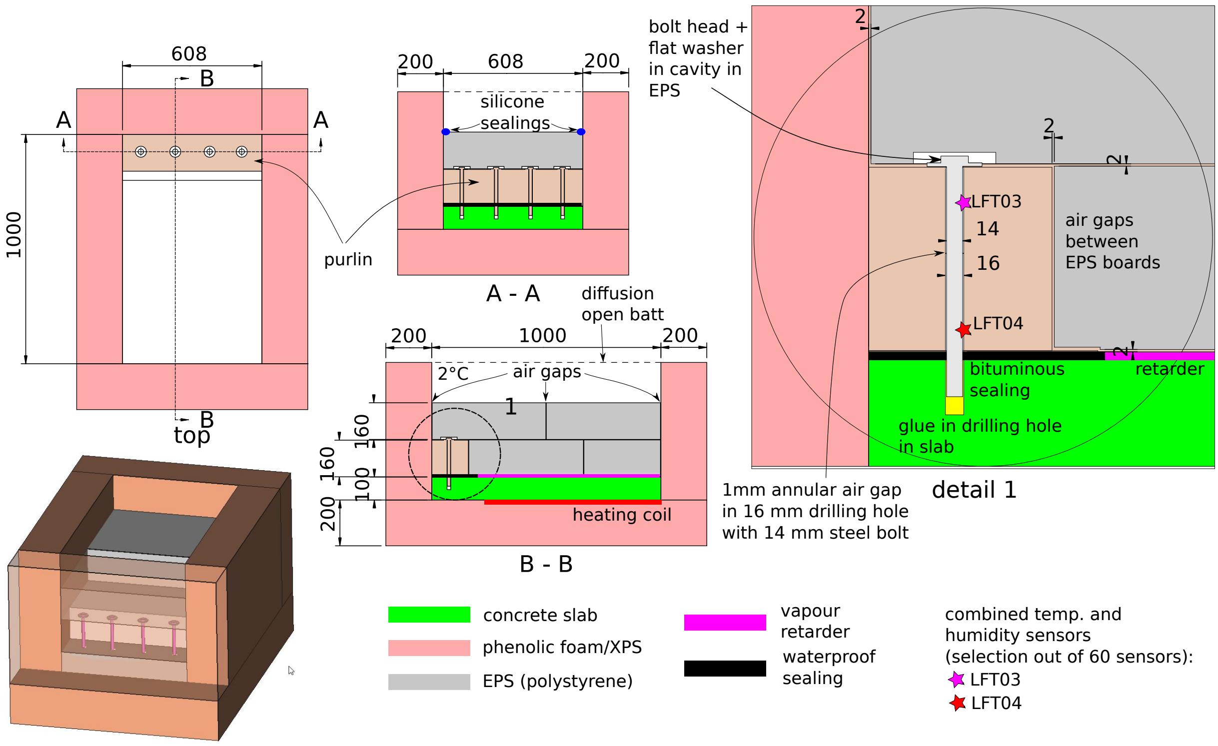

Fig. 3.1: Small replica: Top view (without EPS panels), cross sections of the experiment and detail of the annular gap between drilling hole and steel bolt with sensors. Air channels of about 2mm thickness were kept between the EPS panels. The thickness of the vapour retarder and the bituminous sealing is exaggerated in the drawing.

Large replica Within the revision period of the current article a large 1:1 replica has been erected as shown in Fig. 3.2. Due to several unforeseen circumstances according measurements will start only by the second half of June 2021. The basic construction is the same as for the small replica as described above, in particular also the air gaps between EPS boards. Main differences – apart from the dimensions – consist of the following:

(i) An additional *climate chamber* has been completed (extending an existing one) where the 1:1 replica was fit in.

(ii) A *real roof* consisting of rafters, external sheathing and a roof felt and a brick wall with an ETIC system have been constructed. The roof was not covered by shingles or any other other coverage beyond the roof felt since no relevant effect on moisture transport was to be expected from this finishing layer.

(iii) A *real space* exists below the concrete ceiling (not only a heat mat attached to the slab). Space temperature and moisture are controlled.

(iv) The *ventilation* is mechanically controlled in each attic compartment via fans.

(v) The unconditioned attic is separated into *two compartments*.

(vi) Two variants of *material for the moisture barrier* beneath the purlin are simultaneously tested in a single experiment (see markers in the top view in Fig. 3.2).

(vii) The *insulation material* resting on the ceiling is going to be varied (current setup: EPS. next steps: mineral wool as next step, optional: cellulose, the two latter representing diffusion open materials)

(viii) The *vapour retarder* variants on top of the ceiling are completed by a bituminous sealing as last variant in order to seal off moisture as much as possible from the below the attic.

(ix) A *fire protection board* is mounted onto the purlin's flank flush with the brick wall since this is the current practice of the related construction company for this detail.

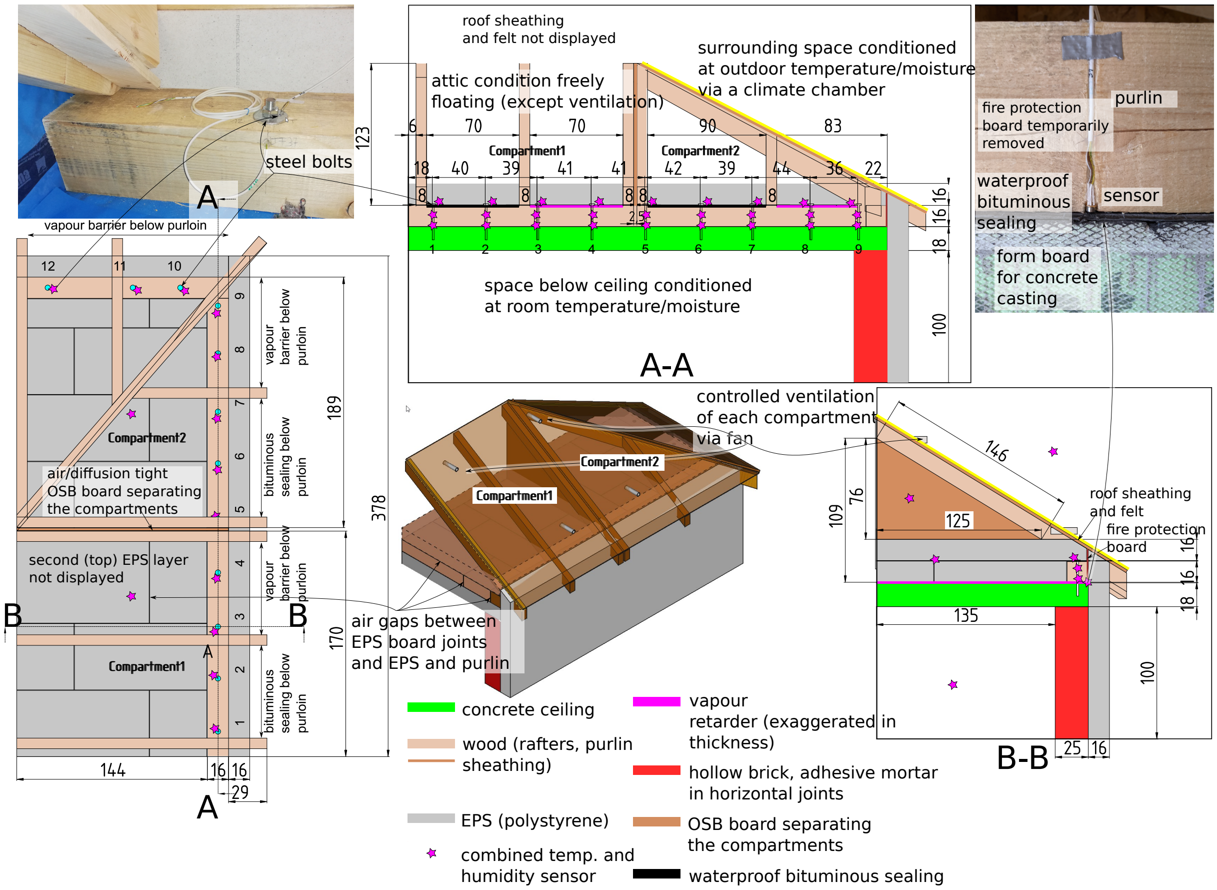

Fig. 3.2: Large replica: Top view (without second EPS layer), cross sections, orthogonal axonometry and two photographs of details of the finished replica. The detail on the bolts, the annular gap and gaps between EPS boards is basically the same as detail 1 in Fig. 3.1 (only a fire protection board as shown in current plan is missing there) and hence not shown here again.

4. Results (only small replica)

4.1. Condensate in both cases

Condensate inside the sample body was found in both cases:

(i) *case A, low sd-value* of the vapour retarder
  (a) During the experiment some sensors gave up their function due to condensate. Destruction started with the sensors closest to the slab.
  (b) Initially at the top edge of the concrete slab a higher temperature was observed (29 °C) than the setpoint of the heating mat (26 °C). The authors attribute this to the hydration heat of the concrete.
  (c) Massive condensate was observed when opening the sample (Fig. 4.1).

(i) *case B, high sd-value* of the vapour retarder
  (a) No more sensors lost their function.
  (b) There was still – though much less – condensate observed at the outer insulation panels, at the one adjacent to the purlin and as well at the other opposite it (Fig. 4.2).

Fig. 4.1: Condensate at the outer insulation with an sd-value of the vapour retarder on the slab of ≈ 0.2 m. Low left: Rusty washers used as distance keepers between the EPS panels.

Fig. 4.2: Condensate at the outer insulation even with a vapour barrier of > 100 m separating the concrete slab from the attic.

4.2. Open question on the vertical moisture distribution in the annular air gap of the drilling holes

One hypothesis at the outset of the project was that humidity might reach the cold attic via the drilling holes in the purlin because the construction company had observed wet spots at the purlin's top around the steel bolt heads.

In the experiment the vertical distribution of the relative humidity in the annular gap of the drilling hole was unexpected with the higher relative humidity being closer to the concrete slab (sensor LFT04 in **Fig. 4.3**). This was surprising since the usual behaviour of water vapour results in a higher relative humidity towards the cold side. The annular gap is 1 mm wide, hence air convection must be taken into account. The situation is complex since it is governed simultaneously by a thermal bridge (steel bolt), convection and highly sorptive (wood) walls of the drilling hole. A literature study on heat and moisture transport phenomena has been carried out. Simulation with the software HAM4D_VIE of TU Wien did not yet show satisfying results with regard to the vertical moisture distribution in the gap:

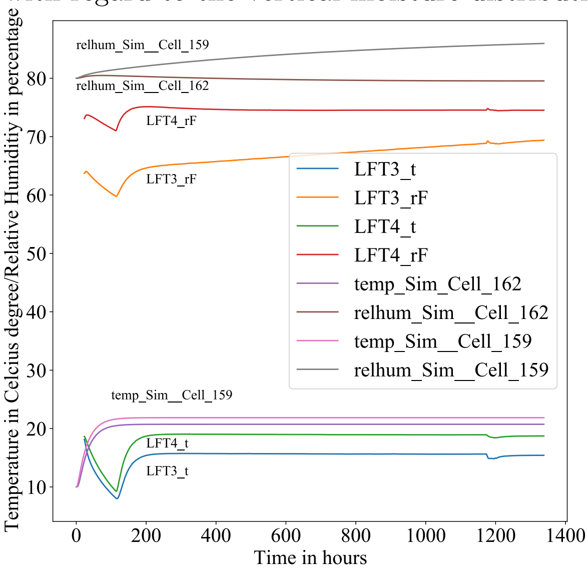

Fig. 4.3: Measured relative humidities and temperatures at the two sensor positions LFT03 (top, colder) and LFT04 (bottom, warmer) and corresponding simulation results obtained with the software "HAM4D_VIE" (relhum_Sim_Cell_162 → LFT03, relhum_Sim_Cell_159 → LFT04)

Natural convection of fluids in an annular gap has been the subject of many studies for fields

of applications such as solar energy collectors, nuclear engineering, cooling of electrical and electronic components according to an overview in [14]. A rough approach for estimating the combined heat and moisture transfer in air gaps is described in [6]. Beyond this no according works have been found on flows in annular vertical gaps in the field of building physics such as drilling holes. The situation of the current project with a small annular gap (1 mm width) and low temperature differences and thus minute air flows makes a direct measurement of air velocities hardly conceivable, thus convection may be attempted to be indirectly inferred from measurement data. An experimental study on mere heat transfer in annular gaps has been done in [5], however, heating and rotating the inner cylinder. A numerical solution for the mere heat transfer via finite differences is described in [3]. A mathematical model for a boiling fluid in an annular gap is described in [11]. An approach with the Lattice-Boltzmann method was taken in [1] comparing the results against a CFD-simulation.
Drivers for the forming of convection loops are the width and the height of the gap [20] as this is also well known in building physics for plane cavities, e. g. between window panes.

5. Conclusion and outlook

(i) A sufficiently high sd-value of a vapour retarder above the concrete slab below cold attics is essential, in particular if the attic is poorly ventilated.

(ii) A second – ongoing – project phase bears on the 1:1 model as described above to examine the role of other parameters such as ventilation and the insulation material.

(iii) It is going to be evaluated if to take the Lattice-Boltzmann approach (recommended for meso scales between macro scales and the purely molecular approach as e. g. in [15]) and/or the classical CFD approach for analysing the impact of air convection within the annular gap but also within the attic space as such. The software HAM4D_VIE was validated up to now only for air flows at much larger scales (pitched roof) than a drilling hole or small gaps between panels.

Acknowledgement
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