Investigation of post-insulated walls with wooden beam ends

Risk analysis for different insulation techniques

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**Abstract** – More and more traditional buildings are undergoing thermal insulation and airtightness improvement. The impact of thermal insulation scenarios on the hygrothermal balance of traditional walls has been investigated in several publications. In this study, the focus is on wooden beam ends embedded into interior thermal insulation. In the context of the East of France, cellulose wadding with smart vapour barrier, glass wool with smart vapour barrier and expanded polystyrene have been added to a brick façade with a wooden beam. Dynamic simulations show the impact of the airtightness of these solutions, the impact of a wooden spacer between the beam and the masonry, the impact of the choice of insulation techniques and the impact of the external coating on the risk of wood decay.

**Keywords** – traditional wall retrofitting; hygrothermal performance; thermal insulation; hygrothermic dynamic simulation

**1. INTRODUCTION**

**1.1 THERMAL INSULATION IN TRADITIONAL BUILDINGS**

While the French law for energy transition has reinforced the insulation requirements of existing buildings and set a significant pace for energy retrofitting (500,000 housings per year), it is important to promote a “responsible” rehabilitation approach for traditional buildings, allowing them to preserve their architectural and cultural values and avoid pathologies potentially generated by the works.

In the north east of France, energy consumption for the heating needs is the highest in the country and the social context means that the region has serious issues with fuel poverty. Public programmes promote different renovation measures with financial assistance, and thermal insulation is one of these [1]. A third of the housing stock in the region is composed of traditional buildings. Researchers and technical teams have proposed guides to help to avoid “unfortunate renovation” such as the publication “Habitat ancien en Alsace” [2].

The impact of thermal insulation scenarios on the hygrothermal balance of traditional walls has been investigated in several publications and tools such as ISOLIN for bricks walls [3]. In the present study, the focus is on one problematic issue with interior insulation: wooden beam ends. The objectives of the work were to assess the risks described in the scientific literature on French cases to
support the technical recommendations for traditional buildings. Comparisons between different configurations and calculated moisture risks could provide useful learning materials for building professionals.

1.2 WOODEN BEAM ENDS AND THERMAL INSULATION IN THE LITERATURE
In their literature review, Kehl et al. [4] confirmed that before insulation, in historical buildings, damage to wooden beam ends is essentially due to lack of maintenance, such as damaged downpipes, leaking roofs and lack of protection against wind-driven rain, or poor material properties.

Concerning wooden beam ends with interior insulation, the literature review states the following points:

• Air connection from the room to the air gap around the beam ends could have a great impact on the relative humidity of the wood, as published by Ruisinger [5];
• The sensitivity of masonry to wind-driven rain is the major factor of risk of decay at the wooden beam end. [4] [6];
• To cut off capillarity transfers between the beam end and the masonry, a hard wooden spacer or a bituminous membrane could be used in Germany in historic buildings. [5] This is not usual in France;
• In some situations, it appears preferable to stop the insulation in a zone around the wooden beams to avoid a large temperature drop and avoid condensation and wood decay as presented in Denmark by Morelli and Svendsen [7].

1.3 FIELD OBSERVATIONS IN THE EAST OF FRANCE
Interior thermal insulation usually has a minimum thermal resistance of 3.7 m²K/W as required to obtain public financial assistance. The main insulation techniques consist of expanded polystyrene, glass or mineral wool with a vapour barrier, wood wool or cellulose wadding with a vapour barrier. Other techniques such as VIP panels or capillary active systems are still relatively rare. It is still possible to find renovation with glass or wood wool without any vapour barrier but use of the latter is spreading. The most highly promoted vapour barrier type is the “smart” vapour barrier with diffusion resistance depending on humidity.

A measurement campaign was performed [8] but without specific wooden beam assessment. However, airtightness around the beam in the vapour barrier plane was checked. Special tapes were used in all cases to tie the vapour barrier to the beam, but the following flaws have been noticed:

• The vapour barrier does not always pass through the wooden floor and is taped on only three faces of the beam;
• The smoke test still shows leakage around the beam ends.

2. SIMULATION METHOD

2.1 CHARACTERISTICS OF THE MODELS
The dynamic calculation program Wufi 2D based on the Künzel model [9] was used to investigate the behaviour of wooden beam ends in cases built
according to the literature review and field observations. Figure 1 shows the configuration.

A solid brick wall with an external coating and a gypsum plaster on the inside is the basis configuration. Three different solutions for internal thermal insulation are applied to add the same resistance of 3.7 m².K/W:

- Glass wool, 12 cm thick plus a smart vapour barrier (sd from 0.2 to 26 m);
- Cellulose wadding, 14 cm thick plus a smart vapour barrier (sd from 0.2 to 26 m);
- Expanded polystyrene, 14 cm thick.

The 15 mm thick external coating could be a lime plaster or a cement lime plaster. Cement plaster was ruled out due to reasons of incompatibility with historic masonry.

Table 1 gives a description of the material properties used for the simulations. The outdoor climate is “Nancy” from Meteonorm, which is the usual representation for the north-east of France except for mountainous areas. The indoor climate was set according to EN 15026 with a normal humidity level. Considering wind-driven rain, the basic value of 70 % for the adhering fraction of rain was fixed for all the simulations.
Table 1. Material characteristics in the models

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<tbody>
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<td>Historic solid brick</td>
<td>1800</td>
<td>0.31</td>
<td>850</td>
<td>0.6</td>
<td>15</td>
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<td>850</td>
<td>0.8</td>
<td>19</td>
<td>45</td>
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<td>0.3</td>
<td>850</td>
<td>0.7</td>
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<td>Glass Wool</td>
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<td>0.95</td>
<td>840</td>
<td>0.032</td>
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<td>Cellulose Wadding</td>
<td>50</td>
<td>0.95</td>
<td>2 110</td>
<td>0.037</td>
<td>1.8</td>
<td>7.9</td>
<td>0.204</td>
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<td>Expanded Polystyrene</td>
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<td>0.99</td>
<td>1 470</td>
<td>0.036</td>
<td>73.01</td>
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<td>Wood beam</td>
<td>650</td>
<td>0.47</td>
<td>1 500</td>
<td>0.13</td>
<td>200</td>
<td>98</td>
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<tr>
<td>Oak spacer</td>
<td>685</td>
<td>0.72</td>
<td>1 400</td>
<td>0.13</td>
<td>140</td>
<td>115</td>
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<td>Lime Mortar</td>
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<td>0.8</td>
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<td>12.07</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Gypsum / Plaster</td>
<td>1721</td>
<td>0.305</td>
<td>850</td>
<td>0.2</td>
<td>13</td>
<td>1766</td>
<td>0.303</td>
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<td>Vapour Barrier</td>
<td>115</td>
<td>0.086</td>
<td>2500</td>
<td>2.4</td>
<td>26,000</td>
<td>6.6</td>
<td>-</td>
</tr>
</tbody>
</table>

2.2 AIR INFILTRATION AROUND THE BEAM AND FLAWS IN THE VAPOUR BARRIER

2.2.1 Air infiltration around the beam

To represent air leakage between the room and the air layer around the beam end in the model, a calculation was made to determine an hourly airflow rate applied as an air change rate per hour in the air layer. According to the publication by Walker [10], the air flow rate is expressed in equation 1.

\[ Q = C \times \Delta P^n \]  

(1)

C is a constant and n depends on the turbulence of the flow; n is equal to 1 in the case of laminar flow. Kalamees et al. have proposed values for C and n in [11] and [12]. For lack of special tape to seal the vapour barrier, 0.188 for C and 0.777 for n, were measured.

\( \Delta P \), the differential pressure, is estimated hourly according to the method in WTA 6–2 [13]. No pressure from a mechanical ventilation system was added as suggested and a conventional floor height of 2.5 m was used to calculate the stack effect.

2.2.2 Realistic airtightness

Perfect airtightness of the insulation material, composed of expanded polystyrene panels or insulation with a vapour barrier is not realistic. WTA 6–2 [13] propose a method to calculate a realistic moisture source behind the insulation layer when the insulation work has been done with “normal care”.

This method was applied and moisture sources have been calculated and integrated into the gypsum plaster just behind the insulation material. These sources are reasonably small, as they represent only small flaws in the
airtightness and not major defects such as a break in the vapour barrier or the lack of joining tape between polystyrene panels.

2.3 RESULT ANALYSIS METHOD
Simulation was performed over a 10-years period and the final years are presented in the results section. Results are given for two façades: the north oriented façade for the lack of sun radiation and the south-west oriented façade for the strong wind-driven rain. Focus is on the following points:

• Indicator A: The part of the wood beam in contact with the spacer or directly with the masonry: the water content as a mass ratio should remain strictly below 30 % and must not exceed 20 % for a total of 8 weeks per year;
• Indicator B: The end of the wood beam in contact with the air layer: the same as previously;
• Indicator C: Relative humidity at the boundary between the insulation and the gypsum plaster: the higher the relative humidity, the higher the mould growth risk;
• More indicators could be useful, such as the risk of freezing but in this study only the three mentioned here are presented.

3. RESULTS AND DISCUSSIONS
3.1 GENERAL RESULTS.
The three solutions for insulation with the two different external coatings and the two orientations were combined to perform 12 simulations with the two infiltration models described in 2.2. A second set of simulations were made without air leakage between the beam end and the room but with a realistic airtightness of the insulation solution. The third set is the same as the second but with a perfectly airtight insulation solution.

On the three sets of simulations, indicator A never exceeds the threshold values but some cases could be close to 20 % of content by mass. This is for the north façade, without an oak spacer and with air leakage around the beam (1st set of simulations). Indicator B exceeds the 20 % by mass threshold for all cases in the first set of simulations, but not in the second and third sets. This indicator is dependant on the airtightness of the insulation solution around the beam. Indicator C changes mainly according to the insulation techniques. The results may represent a risk of mould development in the first and the second simulation sets, especially with expanded polystyrene.

In the followings sections, all the results presented are from the first set of simulations except in 3.2 where the three sets are compared. All simulations are with the hard wood spacer except in 3.1 where its impact is assessed.

3.2 HARD WOOD SPACER BETWEEN THE BEAM END AND THE MASONRY
The oak spacer is used to reduce the capillary absorption of water and in this case the water content at the beam support is reduced by 7 % for both façades.
3.3 IMPACTS OF AIR INFILTRATION AND VAPOUR BARRIER FLAWS

Airtightness around the beam has a clear impact on both indicators A and B. The beam end is more humid with air leakage from the room, especially in winter. In the case shown in figure 4, there is a risk of mould development as the mass water content exceeds 20% throughout most of the winter. The global airtightness of the insulation solution has a clear impact on indicator C.

Figure 2. Impact of the oak spacer on indicator A for a configuration with lime plaster as external coating and cellulose wadding as insulation material.

Figure 3. Impact of air infiltration around the beam end and of realistic flaws in airtightness for a configuration with cement lime plaster as external coating and cellulose wadding as insulation material. (Indicator A)

Figure 4. Impact of air infiltration around the beam end and of realistic flaws in airtightness for a configuration with cement lime plaster as external coating and cellulose wadding as insulation material. (Indicator B)
3.4 NATURE OF THE THERMAL INSULATION IMPACTS

The results on the south-west façade and the north façade are similar. Figures 6 and 7 show indicators A and C for the north.

Figure 5. Impact of air infiltration around the beam end and of realistic flaws in airtightness for a configuration with cement lime plaster as external coating and cellulose wadding as insulation material. (Indicator C)

Figure 6. Indicator A with the 3 different insulation scenarios for the configuration with lime plaster as external coating and north façade.

Figure 7. Indicator C with the 3 different insulation scenarios for the configuration with lime plaster as external coating and north façade.
Indicator B shows no difference between the insulation scenarios. Concerning the wooden beam end, the differences due to the properties of the insulation material are small and polystyrene is the worst solution. At the boundary between the insulation layer and the gypsum, it is more humid with polystyrene. Drying in summer is not possible via the inner surface of the wall.

3.5 OUTSIDE COATING
On both façades, the differences on indicator A comparing cement lime plaster and lime plaster are small with all insulation scenarios. Figure 7 shows the results with cellulose wadding. It is the same for indicator B. According to the literature, a total lack of external rendering would have made a significant difference. Another explanation could be that the climate of Nancy is not a very harsh from the standpoint of wind-driven rain compared to the Atlantic coastal region for instance.

![Figure 8. Indicator A with variation of the external coating for the configuration with cellulose wadding.](image)

4. CONCLUSIONS
Investigations on the risks of decay of wooden beam ends embedded into interior thermal insulation in solid brick buildings in the east of France, confirm the recommendations in the literature. Airtightness around the beam and the quality of the work with the vapour barrier have a significant impact on the humidity of the wood and could lead to wood decay at the end of the beam. In the configurations analysed, the water content in the sensitive part of the wood beam is high and this shows that a proper study should be performed before insulating traditional buildings with wooden beams. Finally, when comparing the most common insulation solutions, expanded polystyrene is the worst solution compared to vapour-open glass wool or hygroscopic and vapour-open cellulose wadding. The results of this study contribute to a guidance for French craftsmen on the retrofitting of traditional walls known as OPERA. The work will continue for other wall types and insulation techniques, such as hard stones or wood wool.

5. ACKNOWLEDGEMENTS
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6. REFERENCES


