

Understanding the Impact of Insulation on Moisture Content of Timber

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Abstract: Retrofitting suspended timber floors can reduce energy demand, but also introduces moisture risks when insulation restricts natural drying. This study investigates the impact of partial spray foam insulation on the drying behaviour of pine timber, focusing on insulation timing, initial moisture content, environmental conditions, and measurement reliability. Pine specimens were conditioned under controlled conditions (20°C, 50% RH and 15°C, 80% RH) and insulated at varying moisture levels. Moisture contents were measured using the gravimetric method and three moisture meters. Results showed that insulation slowed drying compared to uninsulated timber, especially when applied at high moisture contents, prolonging exposure to decay thresholds. Safer outcomes occurred when the insulation was delayed until $\approx 22\%$ MC under moderate conditions, although this was less reliable under cooler, more humid environments. Gravimetric analysis provided the most accurate assessment, while meters often misrepresented values. The findings provide evidence to guide moisture-aware, durable retrofit practice.

Keywords: timber flooring, spray foam insulation, moisture retention, drying behaviour, retrofit risks

1. Introduction

Improving energy efficiency by retrofitting building fabrics alters heat and moisture dynamics, potentially leading to risks if these changes are not carefully managed. These challenges are particularly relevant in the UK, where much housing stock was built before insulation standards were required. (The Climate Change Committee, 2025)

Current retrofit practices often overlook moisture dynamics in timber floors. Yet, uninsulated floors are a significant source of heat loss, despite their prevalence in older UK homes and vulnerability to biological deterioration. (RISE Retrofit, 2024). Timber readily absorbs and retains moisture, making it vulnerable to mould, wet rot, and fungal decay when denied drying pathways. (Aktas et al., 2018; Orr, 2021)

Spray foam insulation is increasingly used in floors for its thermal resistance and airtightness, but its low vapour permeability raises concerns when applied to moisture-sensitive timber. If installed on damp wood, it can trap moisture above critical thresholds for mould and decay. (Historic England, 2016). Although these risks are recognised, evidence for floor assemblies remains limited compared with walls and roofs. (LETI, 2021; RISE Retrofit, 2024)

Existing studies have shown that timber's hygroscopic behaviour makes it vulnerable when moisture remains above biological thresholds – mould risks around 20% MC, with decay risk increasing near the fibre saturation point (FSP) $\approx 30\%$ MC, particularly above 75-80% RH conditions. (Hukka and Viitanen, 1999; Altamirano-Medina et al., 2009; Forest Products Laboratory, 2010). Closed-cell spray foam restricts evaporation and airflow, but existing studies focus mainly on walls and roofs rather than partially enclosed floors. (Historic England, 2016; Health and Safety Executive (HSE), 2024). Evidence is especially sparse on how the initial moisture content when insulation is installed – typically during retrofit works when floors may

not be fully dry – governs subsequent drying and time spent above risk thresholds. This study addresses these gaps experimentally.

This study aims to investigate the impact of partial spray foam insulation on the drying behaviour of near-saturated pine timber under controlled environmental conditions, focusing on moisture retention risks and biological degradation relevant to floor assemblies.

The research addresses the following questions: (i) how partial spray foam insulation alters drying rates and moisture retention compared with uninsulated timber; (ii) how the initial moisture content at the time of insulation influences drying trajectories and duration of exposure to biological risk thresholds; and (iii) how reliably common moisture meters track timber moisture compared with gravimetric analysis during drying.

2. Methodology

The methodology was based on a literature review and laboratory experiments under controlled conditions. Uncoated rectangular pine blocks (45×95×100 mm) were oven-dried to establish reference weights. The test blocks were submerged in water until they achieved high moisture content.

Following conditioning, samples were transferred to a controlled environmental chamber. Two indoor scenarios were tested: 20°C, 50% RH, and 15°C, 80% RH, representing a modern well-insulated home environment and a high-risk indoor environment, respectively. (Karyono *et al.*, 2022). Specimens were divided into six groups of three blocks each: one uninsulated control and five insulated with closed-cell spray foam applied at different initial moisture levels. Moisture content was measured by gravimetric analysis (Equation 1, using oven-dry reference mass) and with three moisture meters: a pin-type resistance meter (Protimeter Mini), a capacitance-based subsurface meter (Testo 616), and a high-range resistance meter (Moist 350) (Figure 1)

Before insulation, readings from multiple surfaces were averaged; afterwards, only the exposed face was measured. Gravimetric analysis was used as the benchmark, as it directly measures mass change and avoids surface bias. Moisture content was calculated gravimetrically using oven-dry mass as the reference.

$$MC = \frac{m_{wet} - m_{dry}}{m_{dry}} \times (100\%) \quad (Eq. 1)$$

Moisture content data were processed in Excel to compare drying trajectories, threshold exposures ($\approx 20\%$ and $\approx 30\%$ MC), and insulation timing, with drying monitored for approximately two weeks per condition.

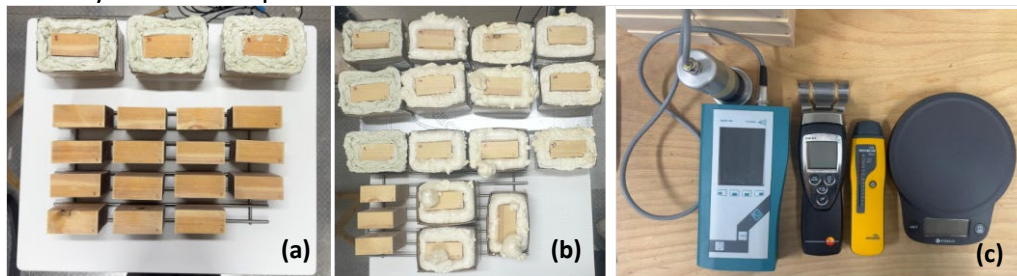


Figure 1: Insulation application and measurement setup: (a) Initially insulated and other groups, (b) final experimental setup, (c) instruments from left to right- Moist 350, Testo 616, Protimeter Mini, and digital scale

3. Results & Discussion

3.1 Moisture uptake

During immersion, moisture content rose rapidly in the first few days, reaching approximately 35-45% by day three. Uptake continued slowly but steadily, reaching around 55-65% on day seven. Beyond the second week, the increase was more gradual, but samples continued to absorb moisture throughout the soaking period. By the end of one month, recorded values ranged between 70 and 85% MC. For several specimens, the daily mass change fell to $\leq 0.1\%$ within 24 hours, indicating that they had reached a near-saturated state with moisture uptake largely complete.

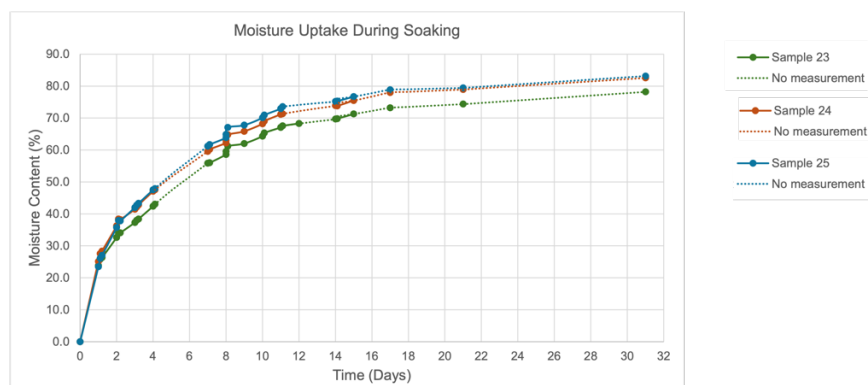


Figure 2: Moisture uptake during the soaking of three timber specimens. The figure presents the soaking process for three representative specimens selected to illustrate the overall absorption trend, consistent across the broader sample set.

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3.2 Environmental effects

Figure 3 shows the drying behaviour of uninsulated control samples under two constant environmental conditions. Starting at $\approx 75-85\%$ MC, samples at 20°C and 50% RH, dried quickly, falling to $\approx 30\%$ by day three, below 20% by day five and stabilising at $12-15\%$. Drying was slower at 15°C and 80% RH: $\approx 50\%$ MC at day five, $\approx 30\%$ at day ten, and nearly $\approx 20\%$ only after day 14. Final MCs remained higher ($\approx 20-22\%$) than in the warmer, drier conditions.

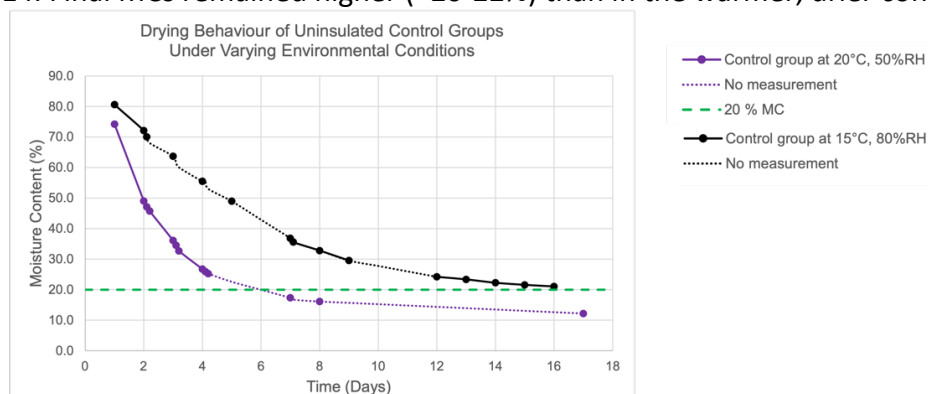


Figure 3: Drying behaviour of uninsulated control groups under 20°C , 50% RH, and 15°C , 80% RH. Environmental conditions significantly influenced the drying process. The findings confirm that timber dries rapidly under moderate indoor conditions; cooler and more humid

environments substantially delay safe drying. These results align with what is already known about how wood absorbs moisture. (Forest Products Laboratory, 2010)

3.3 Insulation timing and drying pathways

The timing of insulation strongly influenced drying behaviour under both environmental conditions (Figure 4).

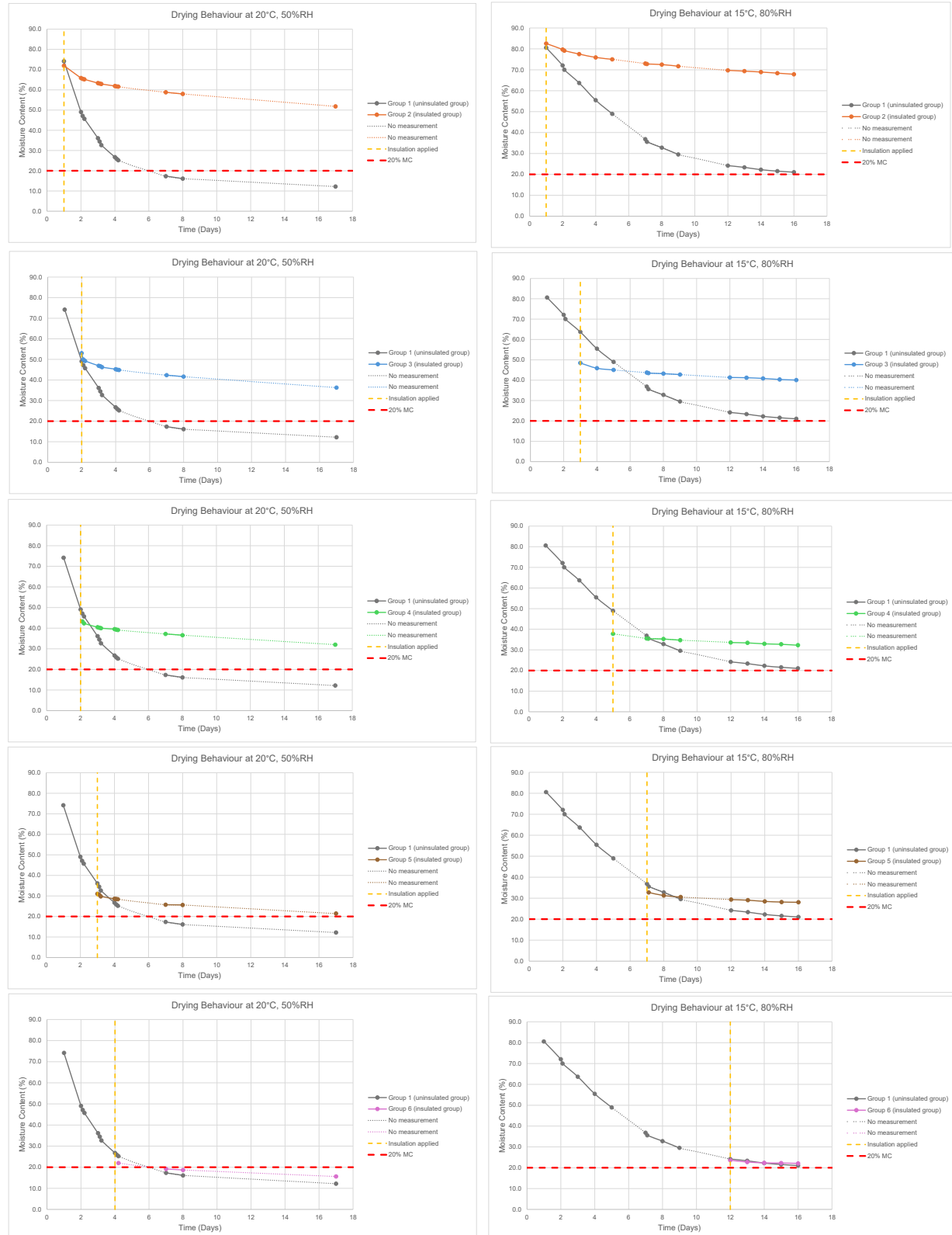


Figure 4: Drying behaviour of sequentially insulated groups compared with the uninsulated control group

At 20°C and 50% RH, the uninsulated control group (Group 1) dried rapidly, reaching safe levels (<20% MC) within five days and stabilising at 12-15% thereafter. Early insulation at ≈70% MC (Group 2) suppressed drying almost entirely, with values remaining >50% throughout. Mid-level insulation (Group 3, Group 4 at ≈40-50% MC) allowed further drying but stabilised above 30%, keeping samples in decay-prone ranges for 17 days. In contrast, later insulation produced more favourable outcomes: Group 5 (≈30% MC) declined to ≈22–25%, while Group 6 (≈22% MC) closely tracked the control, finishing near ≈17–18% MC. Thus, insulation applied above ≈40% MC prolonged exposure above biological thresholds, whereas delaying until ≈22–25% enabled trajectories approaching uninsulated drying. The phase was considered complete once the control (Group 1) and final insulated groups (Group 6) had reached below 20% MC, 20°C and 50% RH. Samples remained in the chamber for one week to confirm stability before starting the following scenario.

At 15°C and 80% RH, drying was slower overall. The uninsulated control only approached ≈20% MC by day 17, not earlier, while early insulation (Group 2) maintained values near 22–25%. Mid-level groups (Group 3, Group 4) stabilised at ≈30-40% with no threshold crossing. Even later, insulation was less effective than under the drier condition: group 5 reached ≈25–28% and Group 6 (≈22–23% MC) plateaued above 20%, with drying rates falling to ≈0.1-0.2% MC per day compared to ≈0.6-0.7% in the control. This indicates that even late insulation prolonged exposure above decay thresholds under cooler and more humid conditions.

The findings confirm that early insulation traps moisture and prolongs exposure above decay thresholds, while delaying insulation until lower MC levels substantially reduces this risk. However, the “safer” thresholds of ≈22–25% MC were observed under 20°C and 50% RH did not hold under cooler, more humid conditions, where even late-insulated samples remained above biological risk levels. This underlines that insulation timing is critical but context-dependent, supporting conservation guidance against applying insulation to damp flooring. (Historic England, 2016). The results also show that uninsulated timber retains stronger drying momentum than insulated samples, reinforcing the risk of locking in moisture when insulation is applied too early. From a practical perspective, this emphasises the need for careful pre-assessment and context-sensitive evaluation rather than reliance on fixed MC cut-offs.

3.4 Reliability of measurement methods

Table 1 and Table 2 compare measurement techniques for uninsulated groups at 20°C, 50% RH, with and without airflow. Gravimetric analysis, used as the benchmark, avoids surface bias by directly measuring mass change. The Protimeter Mini (pin) consistently under-reads, often signalling safe levels prematurely. The Moist 350 (resistance) tended to over-read, rarely drooping below 20% MC and masking improvement. Testo 616 (capacitance) gave intermediate results, tracking trends but sometimes under-representing deeper moisture. Discrepancies were more pronounced in insulated samples, where surface readings diverged from the timber core.

Table 1: Comparison of the moisture measurement methods, showing values below/above the threshold

Measured Moisture Content (%) of Timber Samples Under 20°C, 50%RH								
Measurements	Group X - without airflow				Group Y - with airflow			
	Weighing	Protimeter	Testo 616	Moist 350	Weighing	Protimeter	Testo 616	Moist 350
	Sample 3	Sample 3	Sample 3	Sample 3	Sample 20	Sample 20	Sample 20	Sample 20
Kiln-dried	0.0	0.0	5.6	13.7	0.0	0.0	3.5	12.3
Measurement 1	50.8	28.5	50.0	69.3	59.8	29.0	50.0	66.6
Measurement 2	41.6	25.8	49.3	64.0	34.9	15.5	38.1	45.6
Measurement 3	30.5	20.0	42.5	49.9	22.7	10.7	24.1	27.7
Measurement 4	17.4	10.8	11.2	10.2	15.3	8.6	17.9	23.7
Measurement 5	15.7	10.5	10.3	9.8	14.2	8.8	16.9	22.0
Measurement 6	14.4	10.0	10.2	9.2	13.4	8.3	17.2	21.1
Measurement 7	13.6	9.8	10.2	9.1	12.8	8.6	16.8	21.1
Measurement 8	12.7	9.6	9.8	9.0	12.4	8.6	15.3	20.4
Measurement 9	12.0	9.4	9.4	8.6	11.8	8.4	15.6	22.5
Measurement 10	11.7	7.3	9.1	8.8	11.7	8.4	15.5	20.2

<20% MC >20% MC

Table 2: Comparison of the moisture measurement methods

Instrument	Principle	Typical bias vs gravimetric	Practical note
Protimeter Mini	Pin (surface)	Under-reads	Very responsive at surface; can mislead post-insulation.
Testo 616	Capacitance	Close/slight under	Tracks trends; some under-representation of deeper moisture.
Moist 350	Resistance	Over-reads	Rarely ,20% MC; coservative but may mask improvement

3.5 Implications for retrofit practice

Together, the results indicate that retrofit safety depends on three factors:

- Insulation timing – timber should be allowed to dry to ≈22% MC before insulation; insulating at higher levels sustains decay-prone moisture.
- Environmental context – thresholds should be interpreted cautiously; even ≈22% MC may not guarantee safe outcomes in humid conditions.
- Measurement reliability – gravimetric analysis provides the most accurate measurement, while surface meters risk early-insulation decisions.

These findings refine existing retrofit guidance (Historic England, 2016; Department for Business, Energy & Industrial Strategy (BEIS), 2020), demonstrating with quantitative evidence that insulation can prolong exposure above decay thresholds and that safe practice requires moisture-aware, context-sensitive decision-making.

3.6 Limitations & Research for future work

The study was limited by the accuracy of electronic meters, using an unenclosed balance, simplified constant environments, and a short monitoring period. Variations in initial moisture and focusing on one timber type and insulation product also restrict generalisability. Future work should test different timbers, insulation materials, and full-scale assemblies with extended monitoring under varied, realistic conditions.

4. Conclusion

This study shows that partial spray foam insulation significantly slows timber drying and can trap moisture above biological risk thresholds if applied too early. Insulation timing emerged as a critical factor: safer outcomes were observed when timber was dried to ≈20–22% MC under moderate conditions, though this threshold was unreliable in cooler, humid environments. Gravimetric analysis provided the most accurate assessment of timber moisture, while surface-based meters often misrepresented drying progress and risked early-insulation decisions. Overall, the findings offer rare quantitative evidence to refine retrofit guidance, highlighting that safe practice requires context-dependent thresholds, reliable diagnostics, and integrating moisture-aware approaches into retrofit policy.

5. References

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