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30 January 2026
LIVA/THHN
323791_2

Moisture monitoring – Phase 1: definition and establishment of critical limit values

1. Background and purpose

The Client wishes to follow the moisture conditions at the most moisture-critical locations in the wall cassettes during the construction phase and the operational phase.

The earlier note 323791_LHAM_011 of 1 July 2025 describes, as part of the moisture monitoring, where in the prefabricated wall cassettes Teknologisk Institut considers it appropriate to build in sensors for carrying out moisture monitoring over time in phase 1. These have subsequently, through dialogue with the Client, been adjusted to cover phases 1-3. It is, however, the Client who has the final overview of the logger placements. The Client has in the meantime stated that approx. 50% of the ultimately planned loggers have been mounted in the first phase, but DTI has not received photographic material or a new overview of their final placement.

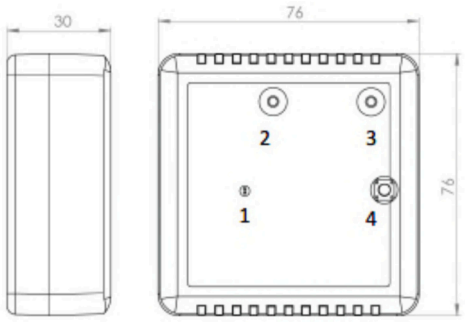

Figure 1. Sketch of the logger type from the User manual for loggers ordered by the customer.

This note establishes, as part of the moisture monitoring, critical limit values for monitoring. These can be used by the Client to set up alarms for the loggers ordered by the Client. Attention is drawn to the fact that the limit values established are dependent on materials, structural build-up, orientation of the structures and the final placement of the data loggers. The limit values and the thresholds for physical investigations are therefore indicative and should be revisited once the system is in operation and after the first annual variation.

2. Definition and establishment of critical limit values

This chapter presents the recommended critical limit values for the moisture measurements that form part of the technical monitoring of the wall cassettes installed in the building. The purpose is to define specific limits for wood moisture content and relative humidity (RH) that can be used as triggering factors in relation to the risk of mould growth for automatic alarms or notifications during the operational and possibly the construction phase. The limit values are set on the basis of applicable guidelines, empirical figures from similar buildings and DTI's experience from assessments of the risk of mould growth, moisture damage and building-related problems. The chapter describes the recommended alarm thresholds, including normal variation levels and the specific thresholds (stated in section 3) where exceedance should give rise to an alarm and possibly destructive opening of the structures.

The Client further states that the loggers also indicate the absolute moisture content. If both outdoor and indoor climate loggers are installed, the difference in absolute moisture content can be used to determine a moisture load class for the indoor climate. Alternatively, outdoor climate data can be obtained from a nearby weather station. Further recommendations are then given for alarms in relation to the operation and measurement stability of the loggers (data loss), as well as measurement intensity/interval.

2.1. Measurement interval

The Institute recommends as a minimum one measurement every 4 hours. This may affect the battery life. The supplier of the loggers has, however, stated by email of 16 June 2025 that with measurements every 4-6 hours a battery life of 6-8 years can be expected.

2.2. Limit values

2.2.1. Wood moisture content

The supplier of the loggers ordered by the Client has stated both general and season-dependent alarm thresholds for the measured wood moisture levels in the document '2024_04_DS Energy_om træfugt_Alarmgrænser', submitted on 5 March 2025. These are expanded on/adjusted below.

Fixed upper limit value for wood moisture content

On the basis of SBi-anvisning 277, a general alarm is recommended at a 48-hour period of 16% wood moisture content or above. If earlier wetting of the timber has been recorded on delivery, or if elevated moisture levels have been recorded during construction/operation, this limit is lowered to 15% wood moisture content, as a reactivation of existing fungal spores in/on the material can occur at this moisture level. No further information has been provided as to which screws are used for installing the loggers, and thereby for measuring the wood moisture content. It is assumed that these are 'ordinary' uninsulated screws. With correct storage and mounting of the wall cassettes, it is therefore assumed that these are dry when the building is erected, and at the same time that any moisture impact can be recorded directly at the timber surfaces.

No lower limit has been set for the moisture level, as this is not considered necessary in relation to the future operation of the building. Any extreme drying-out of the timber would potentially lead to deformation or cracking. Moisture content down to such a low level is, however, only expected to occur in connection with forced drying of any moisture damage. It is therefore not considered necessary to establish lower limits, as this will depend on any drying process and must accordingly be specified in connection with that.

Owing to the reduced ability of the outdoor air to absorb moisture in winter, it may be necessary to raise the alarm threshold. The supplier of the loggers likewise recommends seasonally determined alarm thresholds, with up to 23-24 weight-% wood moisture content in winter. It is recommended, however, to reduce this to 20% wood moisture content in winter.

This tightened alarm in winter can at the same time be used to assess the risk of fungal attack in the structure. For the summer, setting up such an alarm threshold is also recommended.

Marked increase in wood moisture content
Sudden, large increases in the wood moisture content may be an indication of acutely occurring damage that requires a rapid response. An alarm is therefore recommended at an increase of >5 weight-% wood moisture content between two consecutive measurements. The alarm should, however, only be triggered if subsequent measurement points do not fall back to the previous value (i.e. that it is not an erroneous value).

2.2.2. Relative humidity (RH)

In general there is a risk of mould growth at a relative humidity of 75-80%, but this depends on other parameters such as temperature, material type and surface. Seasonal variations are therefore likewise a factor in whether there is a risk of mould growth. DTI therefore recommends that a fixed RH limit value is used only as a reference point, and that this is supplemented with an evaluation of the critical RH for mould growth based on LIM curves (see further description below) as a limit value.

Mould risk – LIM – based on RH measurements
In order to assess the risk of mould growth, the measured relative humidity in the structure can be compared with a LIM (’Lowest Isopleth for Mould growth’) curve. There are three different curves, one for each of:

- Optimal substrate,
- Bio-available substrate,
- Less bio-available substrate.

The function for bio-available substrate is given by:

$$RF_{critical} = \cosh(0.128324\ °C^{-1} \cdot (30\ °C - T)) + 75$$

Where T is the temperature in degrees Celsius and $RF_{critical}$ is the critical limit for the humidity in the structure.

The values used in this formula follow the same model as the one used in the moisture simulation programme WUFI. If the relative humidity at the various measurement points in the structure exceeds this critical humidity over a prolonged and continuous period, a risk of mould growth may arise; see further in section 3.

Marked increase in RH
Just as sudden, large increases in wood moisture content may be an indication of acutely occurring damage requiring a rapid response, the same applies to relative humidity. An alarm is therefore recommended at an increase of 10% RH between two consecutive measurements in the structure. The alarm should, however, only be triggered if subsequent measurement points do not fall back to the previous value (i.e. that it is not an erroneous value).

Increase in RH at low outdoor humidity
As a simpler alternative, a tightened alarm can be set up in case of an increase in RH in the façades at low outdoor humidity, i.e. a humidity below <70%. In that case an alarm at an increase of 5% RH between two consecutive measurements in the structure is recommended

2.2.3. Absolute humidity

Absolute humidity in relation to dew point and critical surface temperature
As stated by the Client, the sensors can report the absolute humidity (AH); this value can be used to assess the dew point temperature (the surface temperature at which condensation will occur) and the critical surface temperature (at which there is a risk of mould growth), respectively. It is not considered, however, that an alarm is necessary, on the basis of the proposed alarms established for wood moisture content and RH.

2.3. Moisture load class

Whereas the LIM value takes account of relative humidity and temperature in the structure, moisture load classes (FBK) can be used to assess the general moisture load from the indoor climate, and can therefore be an indication of changes in user behaviour, poor ventilation, etc. FBK takes account of the moisture supply by looking at the difference in absolute humidity (AH) in the indoor and outdoor climate.

The moisture load classes lie on a scale from 1 to 5, where 1 is the driest (for example dry warehouses or industrial buildings) and 5 is the wettest (for example swimming pools).

If the loggers do not directly report the absolute moisture content, this can be calculated from the following formula:

$$AH = 1000 \cdot RF \cdot P_s / (R_w \cdot (T + 273.15))$$

Where AH is the absolute humidity, RF is the relative humidity, T is the temperature given in degrees Celsius, R_w is the specific gas constant for water, which is 461.5 J/(kg·K), and P_s is the saturation

vapour pressure.

The saturation vapour pressure is temperature-dependent and can be estimated with the Arden Buck equation:

$$P_s = a \cdot \exp((b - T/c)\,(T/(d + T))$$

where a, b, c and d are constants that depend on whether the temperature, T, is above or below 0 °C, which can be found in the table below:

Case \ Constant	a	b	c	d
T > 0°C	6.1121	18.678	234.5	257.14
T < 0°C	6.1115	23.036	333.7	279.82

In order to determine the FBK from either calculated or measured AH values for the indoor and outdoor climate, the moisture supply, i.e. the difference in absolute humidity, must be calculated as:

$$\Delta AH = AH_{outdoor} - AH_{indoor}$$

The moisture load class can then be found in the following ways, depending on the monthly mean temperature of the outdoor air (T_m):

Temperature condition	Determination method Unit for ΔAH in grams of water per m^3 of air		FBK
T_m < 0°C	ΔAH < 2		1
	2 < ΔAH < 4		2
	4 < ΔAH < 6		3
	8 < ΔAH < 10		4
	10 < ΔAH		5
0°C < T_m < 20°C	G(x) = x − T_m · (x − 0.84)/20	ΔAH < G(2)	1
		G(2) < ΔAH < G(4)	2
		G(4) < ΔAH < G(6)	3
		G(6) < ΔAH < G(8)	4
		G(8) < ΔAH	5
T_m > 20°C	ΔAH < 0.77		1
	ΔAH > 0.77		5

It is recommended that the FBK is assessed using monthly averages of the absolute humidity. The moisture supply will typically be higher in winter than in summer. Dwellings with normal occupancy density will, according to SBi-anvisning 277, have a moisture load class of 2, whereas dwellings with unknown occupancy density and without mechanical ventilation will have a class of 3.

2.4. Data loss

There is always a risk of data loss due to either missing or erroneous data. It is therefore recommended that an alarm is sent for missing values after 48 hours, 1 week and 4 weeks of deficient data. Deficient data refers in this respect both to missing signal (and therefore no data) and to unrealistic values. That is to say, the measured RH values must be between 0% and 100%, and the temperature is expected to be between -15 °C and 35 °C for built-in sensors on the cold side of the vapour barrier.

As the sensors are battery-powered, experience shows that it is advantageous to have an alarm if the battery voltage falls below a critical level, so that it can be replaced. This level depends on the batteries used, and the supplier should therefore be contacted for guidance on a relevant limit.

2.5. Further recommendations

As the alarm thresholds set up do not look at whether a moisture accumulation arises in the structure over the years, it is recommended that all measurement data is reviewed at least once a year. DTI can assist with this, if desired. DTI is likewise happy to provide advice regarding any adjustment of measurement limits and limits for physical investigations.

3. Recommendations for limits for physical investigation

On the basis of the limit values established above, together with information from SBi-anvisning 274 and 204, it is the Institute's recommendation that a closer, physical investigation of the structure (by opening up at selected locations) is carried out in the following situations:

- Wood moisture content
  - Limit values for the wood moisture content depend on the season:
    - For the winter half-year, action is recommended if the average wood moisture content is over 20 weight-% for more than 7 days.
    - For the summer half-year, action is recommended if the average wood moisture content is over 16 weight-% for more than 7 days.
  - If a sudden increase of >5 weight-% wood moisture content is recorded which does not quickly fall back to the previous level, and/or the level subsequently stabilises above 15–16%.

- Relative humidity (RH)
  - It is recommended to use the LIM value in relation to assessing the measured RH. If the RH repeatedly lies above the critical LIM value for mould growth at the current temperature (i.e. measured RH is above the calculated $RF_{critical}$ over prolonged continuous periods).
  - As an alternative to the LIM value, the following can be used:

        - If the RH in the structure lies above 75–80% for prolonged periods (4-5 weeks), at temperatures around 15–25 °C.
        - If the RH in the structure lies above 90-95% for prolonged periods (6-7 weeks), at temperatures around 5-10 °C or below.

- Combined indicators
    - If both increased wood moisture levels (e.g. >16–20%) and elevated RH (e.g. >75–80%) are seen in the same area of the structure, particularly if this recurs over several weeks or months.
    - If rising moisture in the structure is recorded at the same time as low outdoor RH (e.g. an increase of >3 percentage points RH between measurements when the outdoor RH is <70%), which may indicate water ingress rather than normal climatic variations.

If any of the above limits are exceeded, it is recommended to contact Teknologisk Institut prior to physical investigations.

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