Reliability of the detection of moisture and mould damage in visual inspections

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Abstract. Moisture and mould damage are common in Finnish public buildings. Due to the possible health hazards of such damage, more efficient detection methods and protocols are needed to examine it. The aim of this study is to examine the reliability of visual inspection in the detection of moisture and mould damage. The study points out that the reliability of all the research material is 70%. The highest reliability values concentrate on those structures where the repair need is highest. However, the range of reliability values is wide: from 0% to 100% depending on the age of building or structure. Reliability is highest in the most simplified structures and lowest in structures consisting of multiple layers of different building materials.

1 Introduction

Different types of visual condition inspection and walk-through inspections are widely used research methods, when moisture and mould damage, and indoor air quality or health issues are the main topics of scientific studies [e.g. 1-5]. However, these studies do not estimate the reliability of the research method used versus thorough condition assessments, which include openings in structures and more specific samplings and measurements. Pirinen [6] estimated that 1/3 of moisture and mould damage is hidden inside structures, so this damage cannot be detected by visual inspections. Pirinen [6] concentrates on small houses in Finland. Haverinen-shaughnessy et al., [7] have assessed the reliability of different building investigation methods, but clear recommendations on how to perform condition inspection have not been made.

The main research questions of this study are to determine the reliability of visual inspection versus thorough moisture performance assessments. The study focuses on Finnish moisture- and mould-damaged public buildings.

2 Inspecting the condition of buildings

Condition assessments and different condition investigations are the most commonly used methods for inspecting the condition and repair needs of buildings in Finland. Condition inspections are visual walk-through inspections mainly focusing on the repair need and normal ageing of structures, materials and HVAC and electrical systems. They result in estimates of the remaining service life and future repair needs. These inspections do not include, for example, the dismantling of structures, material samples or specific measurements. Recommendations and instructions have been given in Finnish national guidelines KH 90-00535 [8] and RT 18-11086 [9]. It is recommended that the condition inspection is repeated at intervals of 5-10 years.

Thorough condition investigations or assessments are much more accurate investigations than visual inspections. These investigations are usually carried out when it is probable that there are some problems or repair needs in buildings. If these problems are connected to moisture and mould damage, the investigation is called moisture performance assessment or building moisture and indoor air quality assessment. These assessments include, for example, the opening of structures, material sampling and measurements, especially different moisture measurements. Recommendations for the assessment are described in greater detail in national guideline [10]. The aim of the assessment is to identify all damage and to present repair recommendations.

Along with assessments and investigations, risk analyses are also used. These may focus on, for example, moisture or indoor air quality risks.

Condition inspections and moisture performance assessments have not prevented moisture and mould damage or indoor air quality problems, so professionals have discussed new routine inspections or methods of checking, which aim to detect critical factors causing such indoor air or moisture issues. The aim is also to eliminate such factors in order to prevent health issues and problems more efficiently in future.

Senate Properties, a company collaborating with the Finnish government in work environment issues and a

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major property owner in Finland, has developed a model in which professionals go through a checklist [11]. From the perspective of structures, this checklist includes 20 topics. These topics are drying structures, control of rain- and surface waters, foundations, ground floors, load-bearing frame and walls, intermediate and uppermost floors, staircases and lifts, external walls and facades, windows and sills, external doors, balconies and terraces, eaves, roof coverings, skylight windows and other apertures, surface materials, sanitary rooms, fixtures, fireplaces and chimneys, and indoor air quality. All these topics are ranked from 1 to 5. Grade 1 means that immediately actions are needed. These actions could be more specific condition investigations or direct repair actions. Grade 5 means that the structure is like new.

The Senate Properties model has been tested in about 100 buildings. The model has proven to be an efficient and operative method for gathering data from numerous buildings and using this data to form a situational picture [12]. However, previous studies have pointed out [e.g. 1-5] that moisture and mould damage can be detected with the naked eye in many cases, so presumably the use of this kind of model not only detects moisture and mould damage, but also other indoor air problems and risks connected to them.

It is critical to evaluate the reliability of the model, something that has not yet been done. Even though the model identifies numerous issues in need of repair, it does not guarantee that the building will be safe and healthy for its occupants. There may be, for example, hidden damage or other indoor air pollutants, the detection of which requires more precise research methods than visual inspection.

3 Research material and methods

The research material consists of 168 public buildings where thorough moisture performance assessments have been performed. This study focuses only on moisture and mould damage in different structures when other indoor air quality problems and impurities are out of scope. Data relating to detection methods of moisture and mould damage has been collected from assessment reports in the moisture and mould damage database. The same database has also been used for analysis in previous studies [13-15] from other perspectives.

Detection methods for moisture and mould damage are listed in Table 1. If one of the following criteria is met in the examined structures, the structure is determined to be damaged. All five detection methods were used in thorough moisture performance assessments. The early detection of moisture and mould damage is done by visual inspection performed by a professional using methods I, II and III as presented in the table. It should be noted that method I includes only clear damage; moisture marks or unclear spots are not counted. In reality, these signs of moisture or mould damage are of course reasons for more closer inspections.

Table 1. Detection methods for moisture and mould damage.

Detection method	Definition	Included in thorough moisture performance assessment	Included in visual inspection
I	Mould damage, visible to the naked eye without magnification.	x	x
II	Unrepaired, active water leakage detrimental to the structure or building material that it wets.	x	x
III	A structure of building material found to be moist, extremely moist or wet by a surface moisture detector based on a five-step assessment scale: dry, a little moist, moist, extremely moist and wet.	x	x
IV	Relative humidity of the structure exceeds 80% in a drill-hole measurement.	x	
V	A material sample shows active microbial (fungal or bacterial) growth. The fungal and bacterial colonies are determined by dilution plating on MEA (2% malt extract agar) agar, DG18 (dischloran 18% glycerol agar) or TYG (tryptone glucose yeast) agar.	x	

3.1 Reliability of visual inspection

The main object of the research is to analyse the reliability of visual inspection versus thorough moisture performance assessments. The moisture and mould damage database include a total of 2,079 separate cases of moisture and mould damage. The detection methods used in each case are listed in the database. If method I, II, III or a combination of these have been used, the damage has been detected in visual inspection and thus detected early.

Every building and every structure were analysed separately, but not every case of damage. An example is shown in Figure 1. Two different cases of moisture- or mould damage were detected in a thorough moisture performance assessment. One of these (marked with '+' in Figure 1) was also detected by visual inspection, whilst the other (marked with '-' in Figure 1) was not detected by visual inspection using methods I, II or III. The reliability of visual inspection in this example is 100%, because at least one case of damage in the external walls was detected.

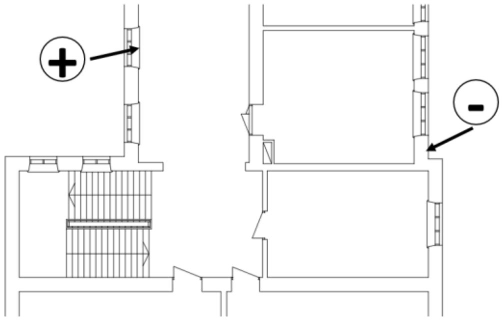

Fig. 1. Damage to the structure is detected if at least one case of damage is detected in a visual inspection. In this example, damage marked with the symbol '+' is detected, but detecting the other damage (marked with the symbol '-') through moisture performance assessment is needed.

It is considered that detecting all moisture and mould damage in a visual inspection is not necessary. The most critical thing is to identify those buildings that need more specific investigation like thorough moisture performance assessment or repair actions. The aim of actual condition investigation or assessment is to identify all different kinds of damage.

In the database, the buildings are divided into six different age groups. The structures are further sub-divided into 14 different subcategories. The age groups are A) 'before 1950', B) 1950-1959, C) 1960-1969, D) 1970-1979, E) 1980-1989 and F) 'after 1990. The structures are divided into subcategories 1) ridge roof, 2) flat roof, 3) slab-on-ground, 4) wooden ground floor with crawl space, 5) concrete ground floor with crawl space, external walls in 6) concrete, 7) timber framing, 8) log, 9) masonry- or 10) mixed frame building, 11) wall in soil contact, 12) concrete intermediate floor, 13) wooden intermediate floor and 14) partition wall. A similar classification was also used in a previous study [15].

4 Results

The research material consists of 168 public buildings. Moisture and mould damage was not detected in five buildings in thorough moisture performance assessments, equating to 3.0% of the examined buildings. In 12 buildings (7.1%), moisture and mould damage was detected in thorough moisture performance assessments, but not in visual inspection in a single structure. In the rest of the buildings (151, 89.9%) at least one of damaged structure was detected in visual inspection.

Table 2. Reliability of early detection in different structures and age groups. All values are percentages [%].

	roof		external walls					intermediate floors				ground floor with crawl space	
	ridge roof	flat roof	wall in soil contact	concrete building	masonry building	timber framing building	log building	concrete	timber	partition wall	slab-on-ground	concrete	timber
Before 1950	91		82		50		83	63	67	75	92		55
1950-1959	62		80	67	83			82		76	78	50	
1960-1969	33	50	83	46		33		100		86	88	80	
1970-1979	33	55	60	47		75		92		67	96	100	
1980-1989	80	100	14	45	0	55		67		77	88	75	
After 1989	0			100				100		100	83		
Totally	68	56	70	50	68	57	86	84	60	78	88	80	65

The reliability of early detection throughout the research material is 70%, which means that 30% of damage was not detected in visual inspection and is so-called hidden damage. Table 2 shows the reliability in different subcategories. The table presents only those categories containing five or more buildings: for example, the research material did not include enough flat-roofs, built before the 1960s. However, the row 'totally' includes all buildings from research material, also those age groups where the number of buildings is below five.

The reliability of visual inspection is highest in slab-on-ground structures (on average 88% of all damage was detected in visual inspection), external walls in log buildings (86%) and concrete intermediate floors (84%). The lowest reliability values were in the external walls of concrete buildings (50%), flat roofs (56%) and external walls of timber-framed buildings (57%). However, on average more than half the damage in these structures was detected in visual inspection. The reliability of visual inspection is, however, as low as 0% in some structures in certain age groups as shown in Table 2.

Figure 2 shows the reliability of visual inspection in those cases where more than five cases of damage were detected in the same age group and structure. The reliability is on average 73.7% and it seems that, when the number of cases of damage rises, so does the reliability of early detection. The higher the number of detections, the lower the effect on individual detections and buildings.

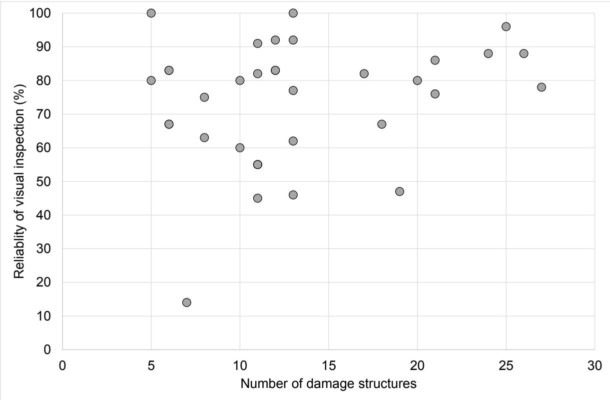

Fig. 2. Reliability of visual inspection, and moisture and mould damage repair need.

4.1. Correlation between reliability of visual inspection and repair need

The correlation between early detection and moisture and mould damage repair need is presented in Figure 3. The correlation coefficient is 0.244 over the entire research material. The highest reliability values (reliability over 90%) were obtained irrespective of repair need. The lowest reliability values (reliability below 40%) are concentrated in those structures where the repair need is lowest (below 50%). The presented repair need of structures is based on the author's previous study [15].

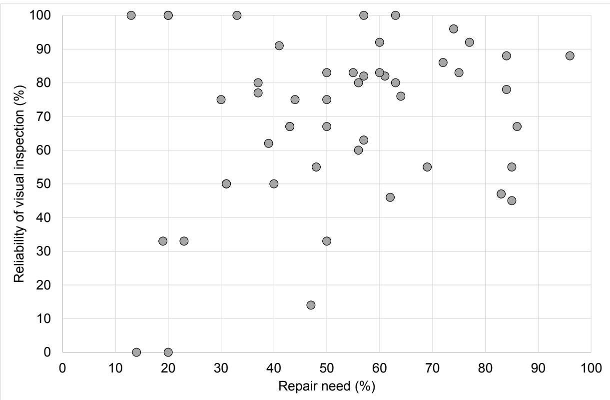

Fig. 3. Correlation between repair need and reliability of visual inspection.

The correlation coefficient may be a competent indicator when differences between structures and age groups are being studied. However, the amount of data in these subcategories is too low for this kind of analysis. Figures 4-13 shows the correlation between the reliability of early detection and the repair need for moisture and mould damage. External walls in log buildings, wooden intermediate floors and wooden ground floors are not presented due to the scarcity of data. The repair needs of these structures are 50%, 43% and 85%, respectively, and the reliability of visual inspection 83%, 67% and 55%, respectively as shown in Table 2.

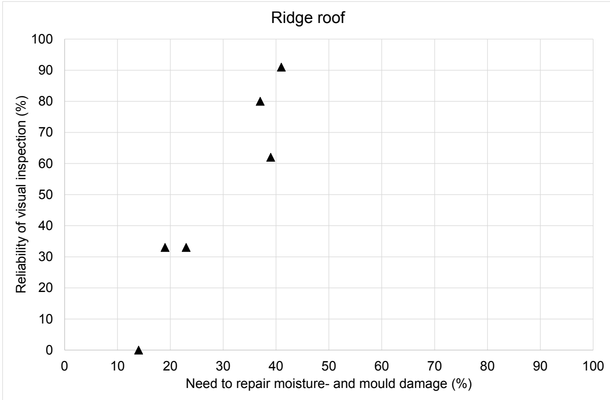

Fig 4. Correlation between repair need and reliability of visual inspection.

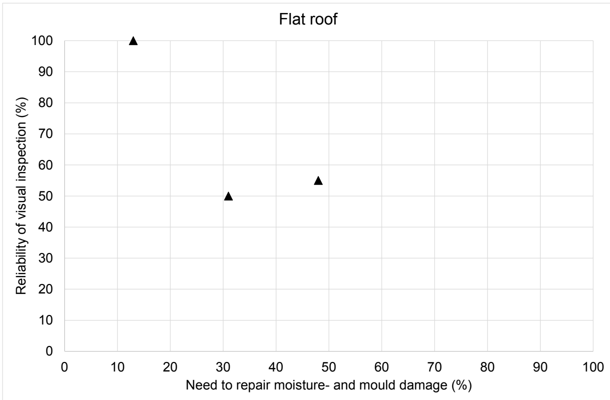

Fig. 5. Correlation between repair need and reliability of visual inspection.

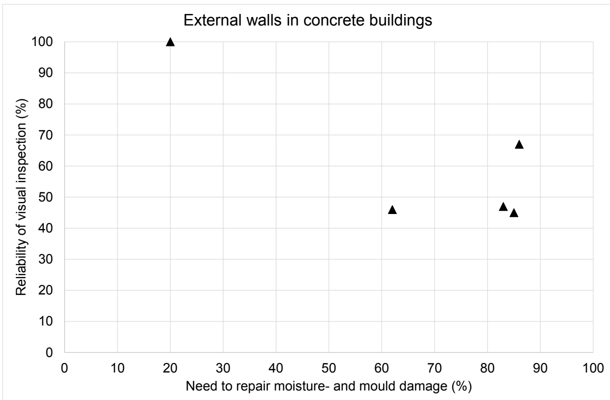

Fig. 6. Correlation between repair need and reliability of visual inspection.

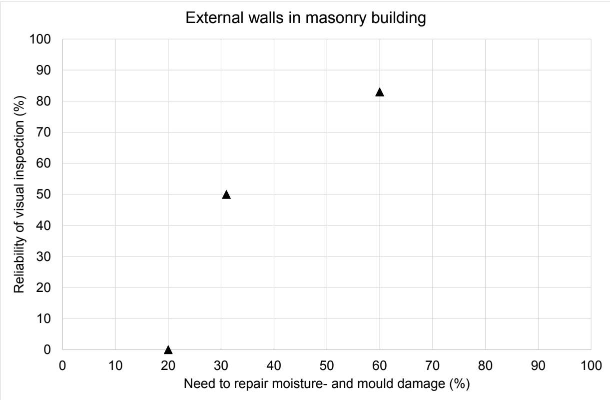

Fig. 7. Correlation between repair need and reliability of visual inspection.

Fig. 8. Correlation between repair need and reliability of visual inspection.

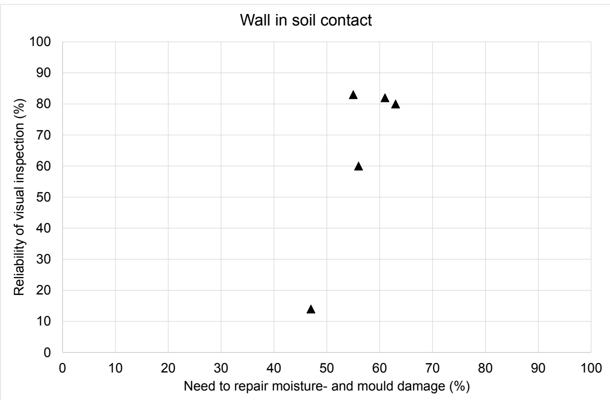

Fig. 9. Correlation between repair need and reliability of visual inspection.

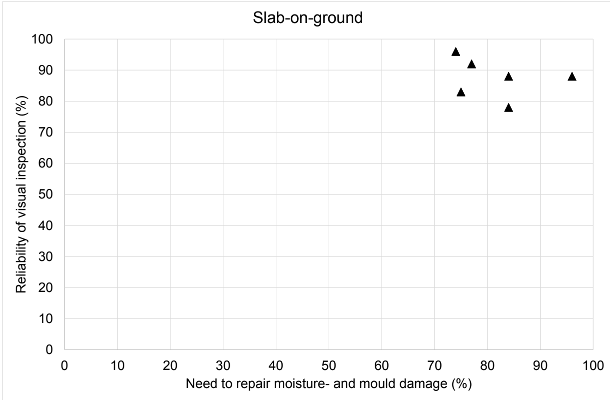

Fig. 10. Correlation between repair need and reliability of visual inspection.

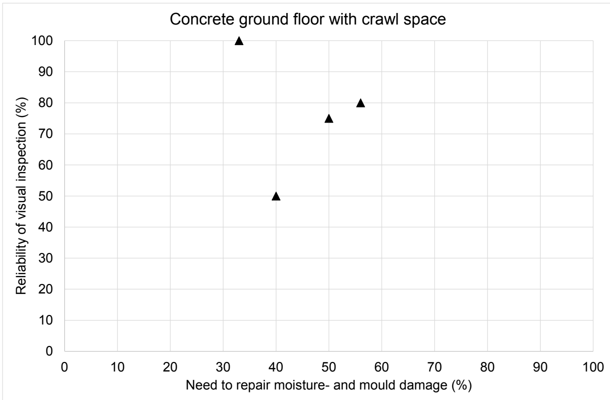

Fig. 11. Correlation between repair need and reliability of visual inspection.

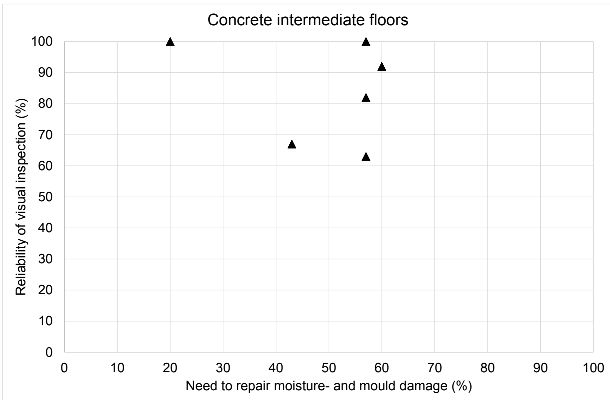

Fig. 12. Correlation between repair need and reliability of visual inspection.

Fig. 13. Correlation between repair need and reliability of visual inspection.

5 Discussion

The reliability of early detection is highest in the most simplified structures as shown in Table 1. Log buildings, concrete intermediates floors built after the 1960s and slab-on-ground structures could be counted in this category in Finnish public buildings. These simplified structures consist of their main material and coatings when observed from inside the building. The most sensitive building material is usually located near the inner surface of structure, so the condition of the material and structure can be examined without dismantling the structure. The capillarity of these structures is usually high, which also moves moisture to the surfaces of the structures.

The reliability of early detection is lowest in the most complicated structures as shown in Table 1. Timber-based structures (ground floors with crawl space, external walls, intermediate floors, flat roofs) and external walls in concrete buildings could be counted in this category in Finnish public buildings. These structures consist of multiple layers of different materials and the most sensitive building material may be located inside the structure, so damage to that material cannot be detected without dismantling the structure.

These findings highlight the need to open these structures and sample the material in a thorough moisture performance assessment, as a visual examination could not detect problems or damage.

On average, the reliability of visual inspection is over 50% in every structure and 70% in total. It is therefore clear that, if walk-through inspections are used, they will highlight numerous cases of moisture and mould damage or the need for more precise condition inspections like moisture performance assessments.

When the correlation between the repair need of structures [15] and the reliability of visual inspection is compared (see Figure 3), it is important for reliability to be high when the repair need is high. None of the Figure 3 dots are located in the section of greatest risk: the low reliability of visual inspection (below 30%) and high repair need of moisture and mould damage (more than 50%).

Some dots in Figure 2 are located in the area where the reliability of visual inspection and repair needs are low. In certain buildings, such hidden damage may result in indoor air quality problems, but in the building stock as a whole these are not so remarkable. The lowest reliability values are from the external walls of masonry buildings and ridge roofs. As could be noted from Figure 3 and 6, the reliability of visual inspection in these structures rises as the repair need rises. The correlation coefficient of these structures is 0.95 and 0.93, respectively.

The tested model of Senate Properties [11, 12] has shown that walkthrough inspections detect moisture and mould damage and other risks connected to indoor air quality. However, the reliability of this model has not yet been studied, so it is unclear whether these findings will prevent indoor air quality problems in future. Moreover, there is a risk that the use of this kind of model will lead to a situation where property owners focus only on a few major issues, and hidden damage and its influence on indoor air quality are not considered. According to previous studies [e.g. 6, 7], some moisture and mould damage is hidden and cannot be detected without dismantling structures. In sum, walkthrough inspections are no substitute for thorough moisture performance assessments.

Lappalainen et al. [1] have pointed out that walk-through assessments can be used to determine the relative importance of repairs in moisture- and mould-damaged buildings. The results of this study are similar to previous studies [1, 11, 12]: walk-through inspections are useful tools to determine the condition and repair needs of multiple buildings, but major repair measures should still be based on thorough moisture performance assessments.

This study focuses only on buildings with problems, so it is unclear what the reliability of visual inspection would be if also used in the reference buildings. The tests of the Senate Properties model [12] have also concentrated on buildings where numerous problems and findings have been expected. It seems that property owners in Finland fear that studies using these kinds of models may identify new and as yet unknown problems connected to indoor air quality. These new findings could result in unexpected costs for property owners, so this fear may be a reason why buildings without indoor air quality problems are not included in the studies. It has not therefore been possible to carry out random sampling of the condition of the entire building stock. The condition of reference buildings or genuine random sampling should be included in some future studies.

The research material consists of thorough moisture performance assessments. It is probable that not every visual observation is mentioned in reports. This applies especially to those situations in which the condition investigator has carried out more precise measurements such as the dismantling of structures, material sampling or moisture measurements. Knowing all visual observations would probably improve the reliability of visual inspections.

The building stock includes many so-called risk structures in Finland. These are structures where moisture and mould damage are common, and in many cases, damage is hidden and severe. The greatest reason for damage is usually the poor thermal and moisture behaviour of structures under current moisture stresses. The risks of these structures are identified afterwards, so the structures are no longer used. The risk structures of buildings were outside the scope of this study but knowing them would improve the detection of hidden damage and especially the need for further condition inspection.

6 Conclusion

The total reliability of the visual inspection of moisture and mould damage is on a good level: 70% of moisture and mould damage can be detected in visual walk-though inspections, which includes surface moisture measurements. Reliability is highest in the most simplified structures and lowest in structures consisting of multiple layers of different materials. Timber-based structures (ground floors with crawl space, external walls, intermediate floors and flat roofs) and external walls in concrete buildings are structures where the reliability of visual inspection is lowest: 65%, 57%, 60%, 56% and 50%, respectively. Reliability is highest in the most simplified structures such as slab-on-ground (88%), external walls in log buildings (86%) and concrete ground floors with crawl space (80%).

The findings of the study indicate that walk-through inspections could be used to determine the condition of multiple buildings, but more precise moisture performance assessments are still needed when it is a question of multilayer structures and the repair of a whole building.

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